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HEAT

CHAPTER I

THE NATURE OF HEAT AND HOW IT IS MEASURED

WHAT is heat?

Oftentimes the simplest question regarding every day phenomena will confound the wisest philosopher. We become so familiar with effects that we rarely bother ourselves with the causes. We do not distinguish between familiarity and knowledge. Could we but see all that happens when a match burns, we would be the witnesses of a battle, beside which all the conflicts of men with men would pale into insignificance. Thousands of trillions of molecules clashing with enormous velocity against each other. Countless brigades of contestants forming and reforming into line of battle. Grand divisions of molecules, almost infinite in number, hurled upon other divisions, make Pickett's famous charge at Gettysburg seem like a child's game with toy soldiers, if we consider only the units in the struggle. Could we but see all that takes place within a bar of iron when we either heat or cool it, the definition that "Heat is a form of motion" would readily be understood.

Matter is made up of particles called molecules, so small, that Sir William Thomson estimated that if a drop of water were magnified to the size of the earth, the molecules of water would each be less than the size of an ordinary baseball and larger than small shot. When we apply heat to a bar of iron, these molecules, which are forever moving, move a little faster. On the other hand, if we cool the iron, they move a little slower.

The same thing is true of a liquid or of a gas. There is this difference, though, in the character of the molecular motion in the three conditions in which matter exists:—In solids, the molecules move back and forth, just like tiny pendulums; in liquids, the molecules wander all around without any apparent aim, and in no regular path; in gases, the motion is supposed to be in perfectly straight lines. If we could stop the motion of the molecules in a body, the temperature of that substance would immediately drop to no temperature at all. This point, called the "absolute zero," has never been reached, although, as in the case of helium, we have come within close hailing distance of it. We are, therefore, unable to improve upon Tyndall's definition, that heat is a mode of motion. The more motion of the molecules, the higher the temperature of the body; the less motion, the less temperature, and, were the tiny particles of matter known to us by the name of molecules, absolutely without motion, there would be absolutely no heat.

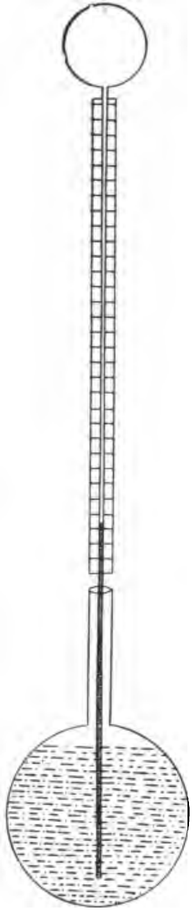


Fig. 1.
Air Thermometer

We are all familiar with the effects of heat upon the body, and readily recognize the presence or absence of heat by our perception of temperature. The body, however, is an unsafe guide to the real condition of substances with respect to their temperature. A person, returning from a walk in zero weather, entering a hallway where the thermometer registers 50° F. has the impression that the hall is warm, while some one else, who enters the same hall from a room where the temperature is 75° F., considers the hall to be quite cool. Hence the need of some instrument which will tell us exactly the condition of a body with respect to its temperature. This instrument we have in the common thermometer.

The first practical thermometer was invented by Galileo, prior to the year 1597, and consisted of a glass bulb, filled with air and dipping into a vessel containing colored water (Fig. 1). When the air in the bulb became hotter, its molecules moved faster and exerted more pressure upon anything with which they came in contact. They consequently pushed the liquid down the tube. When the air cooled, the reverse happened and the atmospheric pressure forced the liquid up the tube. This tube is marked with an arbitrary scale. It was soon found that in order to rise to the dignity of an accurate measurer of temperature, the thermometer must be fitted with a standard scale. The temperature at which water boils was finally

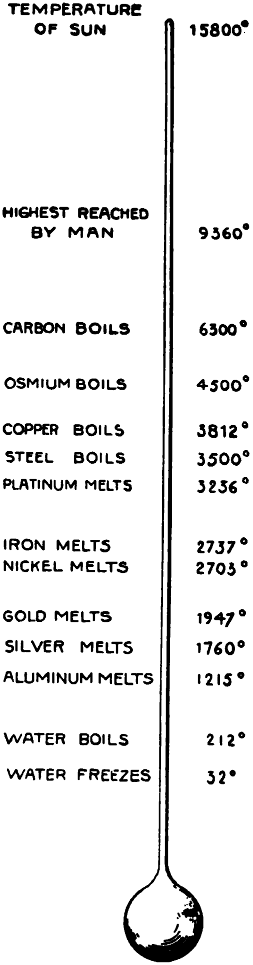


Fig. 2.—Heat Table

adopted as one of the important markings, while the freezing point of water was adopted as the other. In the Fahrenheit scale so commonly used in the households of this country and England, the boiling point is placed at 212°, and the freezing point is 32°. It is interesting to learn how Fahrenheit figured out these odd, cumbersome numbers as the chief points in his scale. He planned to make a thermometer that would tell the absolute truth about the temperature of a body. He did not want to begin his scale with the freezing point of water, as he knew quite well that there was a lower degree of temperature. Fahrenheit was living in Dantzic at the time of his experiments, and knew from many years' experience just how cold it is in that city in the coldest weather. He found that he could exactly reproduce this temperature, anytime, anywhere, by mixing salt with pounded ice. This temperature, he concluded, was the lowest limit of heat, since neither nature out of doors, nor man in his laboratory, could go any lower. Accordingly he put some mercury into a tube and bulb, plunged it into a mixture of salt and ice, and scratched a zero mark on the glass at the top of the mercury column. This he deemed to be the absolute zero. He then calculated the mercury volume at that temperature and found it to be 11,124 parts. Next he placed the same thermometer in a mixture of ice and water. The mercury promptly expanded and occupied 11,156 parts by volume, or 32 parts of an increase over the zero volume. Accordingly he scratched the number 32 at this new height of the mercury column, and called it freezing point of water. Next he placed the thermometer in boiling water. The mercury expanded to 11,336 parts or 212 parts higher than zero. This he called the boiling point of water. He divided the scale between 32 and 212 into 180 equal divisions, which he called degrees, and his scale was complete. We shall see later that Fahrenheit was very much mistaken in his belief that he had reached the absolute zero of temperature, as that point is about 459° below where he conceived it to be. Ice at Fahrenheit zero is red-hot as compared with the temperature of liquid air.

The Centigrade scale, used by scientists everywhere, is simpler than the Fahrenheit, in that it has 100 steps or degrees between freezing and boiling.

Mercury is the liquid commonly used in the construction of thermometers. It expands and contracts more than the glass tube in which it is contained, and therefore is used as an index which points out faithfully the rise and fall of temperature. Mercury, however, has its limitations as a temperature marker, since it solidifies at about 38° below zero on either scale, and boils at 674° F. The boiling point of mercury may be considerably raised, however, on the principle that the boiling point of a liquid rises with the pressure exerted upon it. If the space above the mercury in a thermometer be filled with an inert gas like nitrogen or carbonic-oxide, the pressure of the gas will constantly increase as the mercury rises, and prevent boiling even at 950° F. At this temperature, however, the glass begins to soften, and renders its use impracticable. By using fused quartz, the latest friend of the chemist and physicist, as a thermometer tube, mercury may be used for the determination of temperatures as high as 1300° F. For temperatures below the freezing point of mercury, it is quite evident that some other substance must be used. Alcohol is most generally used, but such thermometers are very irregular in their action. Alcohol freezes at —168° F. Pentane is very useful in the construction of low temperature thermometers as it remains liquid at the exceedingly low temperature of —328° F. For the determination of temperatures still lower than this, a gas thermometer must be used. The hydrogen thermometer is the final court of appeal, to which all the readings of the other types of thermometers must be referred, as regards both high and low temperatures.

The manufacture of the modern thermometer has been brought to a high degree of scientific accuracy, and an outline of the process may not be uninteresting. First of all, glass tubes are drawn out to lengths sometimes exceeding 300 ft. When cool, these tubes are cut into lengths of about 4 ft., called "canes." These canes are carefully inspected and only those that have an approximately uniform bore are accepted. This means that only about three or four out of 75 canes are passed, the rest being "scrapped" as imperfect. The uniformity of bore of a thermometer tube is the important element in the manufacture of tubes. In some thermometers this bore is finer than the finest hair, although it looks to be larger, owing to the magnification produced by the curvature of the glass around it. These canes are next cut into suitable lengths, and glass bulbs are blown at the end of each. A large bulb with a small bore tube will make an "open range" thermometer, while a small bulb and a large bore tube will produce a thermometer where only slight movements of the mercury column are required. The bulb and tube are then heated to a very high degree in order to drive out as much of the air as possible; while hot, they are plunged, open end down, into mercury, and the mercury is then forced up into the tube by atmospheric pressure, as the tube cools. This is repeated a number of times, until the requisite level is reached. These tubes are again strongly heated in hot sand to expel the last trace of moisture. The bulb is next heated in a Bunsen flame in order to boil the mercury and drive out the remaining air. It is then cooled in ice water and the tube cut off very close to the length of thermometer desired. The top part of the tube is now drawn out until it is very thin, but still traversed by a minute hole at the center. Strong heat is once more applied and the mercury made to fill every portion of the bulb and tube, and some of the mercury escapes through the minute hole. At this instant a hot blow-pipe flame is turned upon the upper end of the tube and it is sealed. The tube is then complete and ready for graduation. It is laid upon a strip of metal and lines are scratched upon this blank, showing the height of mercury at what are termed "test" points, generally 32° and 92°. This scale is then subdivided by machinery into the subdivisions required by the distance between these points, varying from an inch or so, to the hundredth of an inch. This scale is kept for the thermometer which determined its points, as no two thermometers have exactly the same scale. Should the tube be broken, the scale is of no use as it would fit no other thermometer. When a high-grade thermometer is sent out, there is always sent with it a slip of paper, showing its variations from the true standard, between different points. This is necessary from the fact that it is absolutely impossible to make a tube of uniform bore, and the expansion is therefore unequal. Every thermometer is therefore compared with one that is as near perfection as possible, and the necessary corrections noted. Strange to say, a thermometer, in order to be reliable, has to be seasoned. Certain molecular changes take place in the structure of the glass and these can be determined only by careful observation over a period varying from one to two years. The thermometers are kept in a vault for that length of time, and are regularly inspected and the change in bore noted. After the thermometer has passed all these examinations it is put on sale, and if we are inclined to grumble a little at the high price asked for a few ounces of iron, glass, and mercury which make up a thermometer, we should remember that it is skilled labor, not material, for which we pay.

Another type of thermometer is one which depends upon the well-known fact that under the same degree of heat different metals expand at different rates. Two ribbons of dissimilar metals, like steel and brass, are firmly soldered together and coiled into a spiral. Owing to the unequal expansion of the two metals, this spiral becomes longer or shorter as the temperature varies. This movement of the spiral is magnified by a series of delicate levers, and is shown in the movement of a hand on a dial bearing a scale that has been graduated into degrees. Metallic thermometers are unreliable. After a time, the molecules of the metals become set, and refuse to act exactly as before. This is not true when the highest grades of steel and brass are used.

Mercury thermometers answer all ordinary requirements for domestic and industrial uses, but they fail utterly when we attempt to use them for measuring high temperatures. We are compelled to use for this purpose an instrument known as a "pyrometer" or "fire measurer." The simplest pyrometer is a rod of graphite enclosed in a tube of iron. The graphite expands and contracts more than iron, behaving just as the mercury and glass in a mercury thermometer. There is a limit to the use of this pyrometer as the very high temperatures met with in furnace work will melt the iron and boil the carbon. Carbon has the curious property of boiling before it reaches its melting point.

A strip of platinum is sometimes used as a pyrometer. It is heated by a current of electricity to a white heat, the temperature of which is 3400° F. An ordinary thermometer is placed, say three or four feet away from the white-hot platinum strip, and the rise in degrees noted. Then the same thermometer is placed near to the furnace whose temperature is to be estimated. When the exact distance is determined by experiment in order that the thermometer may indicate the same temperature as was shown when used with the platinum strip, it is then receiving the same heat from the furnace as it had previously received from the heated platinum. Now, heat varies inversely as the square of the distance from its source. If the thermometer receives the same heat from the furnace as it had previously received from the strip, but at twice the distance, then the furnace is four times hotter than the strip. This method is known as "radiation," is necessarily unreliable, and is only used for approximation.

We now turn to electricity as our temperature measure, and here we have the most accurate appliance known to science for this purpose. Some years ago the late Professor Langley invented an instrument which he called a "bolometer." This wonderful invention is capable of determining very slight changes in temperature, so slight as the millionth of a degree. It is used in connection with an instrument known to electricians as a "Wheatstone bridge." This bridge corresponds to a very sensitive pair of scales or balance. The slightest variation in a current of electricity may readily be detected. One of the four arms of the bridge used by Langley, is an exceedingly thin strip of platinum—the bolometer.

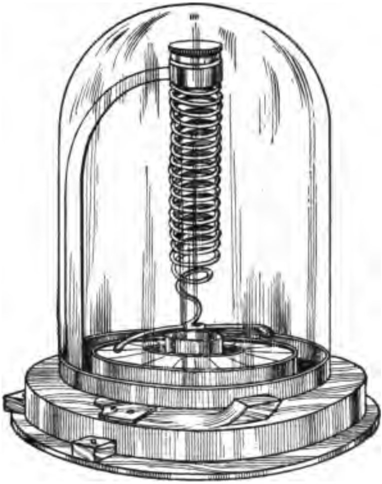


Fig. 3.—Metallic Thermometer

This platinum strip was made by first plating copper with a thin film of platinum, and then dissolving the copper with nitric acid. The film was only one thirty-two-thousandths of an inch in thickness. The electrical resistance of a conductor increases with its temperature. When the thin platinum strip was subjected to the slightest heat, its resistance rose, and the increase in temperature could readily be calculated from the change in the value of the electrical current.

The bolometer, however, is really a laboratory instrument, and would not be available for furnace work. In order to arrive at the temperature of a blast furnace, we are therefore compelled to take advantage of another curious property of metals, with respect to their relation to electricity and heat. If two dissimilar metals, such as antimony and bismuth, or platinum and rhodium, have a common point of contact, a slight current of electricity will be produced if this junction be either heated or cooled. The two elements are called a "thermo-electric couple." These couples, like the bolometer, are to be used in connection with a Wheatstone bridge, and the temperature of the furnace calculated from the slight change in resistance produced by the unequal heating of the dissimilar metals.

These couples may be placed directly in the furnace, provided the platinum-rhodium couples are used. Should the temperature rise above the melting point of either of the metals, the radiation rather than the direct method must be used. Le Chatelier's thermo couple, of which one element is platinum, and the other platinum containing 10% of rhodium, is in common use, and permits of measurements as high as 3100° F.

It is hoped that sometime a couple may be constructed whose elements will consist of two varieties of carbon, but this has not yet been done.

With all forms of pyrometers, after a certain temperature has been reached, temperature calculations as to the precise degree, cease to be accurate, and must necessarily be approximated.

Other methods for determining high temperature, such as vapor-tension, dissociation of metals, fusion and specific heat, have been devised, but none are better than the form known as Le Chatelier's. The melting points of lead, silver, gold and palladium all lie within the range of this instrument. It is of especial value in the treatment of porcelain and ceramic ware generally, and has almost revolutionized this important industry.

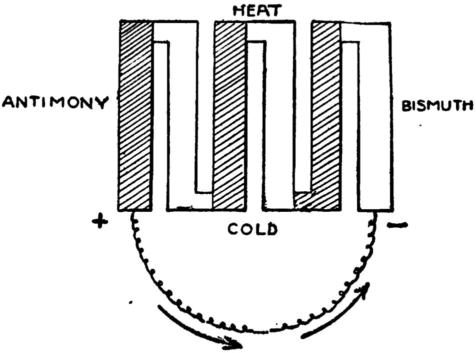


Fig. 4.—Thermo-Electric Couple

CHAPTER II

HOW LOW TEMPERATURES ARE PRODUCED

THE principle underlying the production of low temperatures is very simple and easily understood. It depends upon the warfare that constantly exists between heat vibrations and the cohesive force that holds matter together. If matter be heated, the cohesion between the particles is lessened, and if sufficient heat be applied, the matter changes from the solid to the liquid form, and then to the gaseous—a triumph of heat vibration over its antagonist, cohesion. Conversely, if we drive matter into closer relationship between its component particles, in other words if we compress it, the heat vibrations are driven out, and cohesion is the victor.

Expansion absorbs heat. Compression sets it free. Everyone is familiar with the fact that when we squeeze air into a smaller space, as for example when we pump it into a bicycle tire, the pump soon becomes quite hot. Whence the heat? It is the result of forcing the particles of air closer together, thus setting free the energy which had kept them farther apart. Likewise, every observer knows that an enormous amount of heat must be given to water at the boiling point to induce it to become steam; and further, that the temperature of the steam given off, if not confined within a boiler or other container, is exactly the same as the temperature of the boiling water. Steam is simply expanded water, and the heat energy essential to its production does not change its temperature. What, then, becomes of this heat energy? The answer is easy. The heat is transformed from energy of motion to energy of position and is given to the molecules of water as the admission price to the realms of steam. It becomes that which serves to give the molecules of steam the freedom of motion and consequent increased volume which constitutes the difference between a liquid and a vapor. (Fig. 1.)

Since this heat is lost to measurement, but reappears upon the condensation of the steam, the name, "latent heat," was given to it by the early philosophers. A cubic inch of water absorbs a comparatively large amount of heat when transformed into steam. The steam, however, will occupy the space of a cubic foot, over 1,700 times the original bulk of water. Should this cubic foot of steam be squeezed into one cubic inch of space, it would again assume the liquid form, and the heat energy which permitted it to become a vapor, would become sensible and available for other work. In changing matter from one

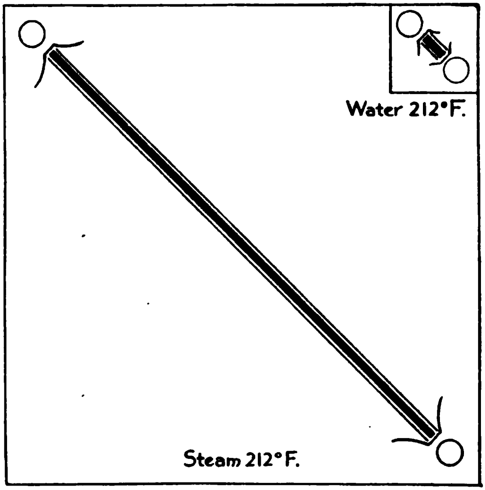


Fig. 1.—Water and Steam at 212° F. The heavy bars represent diagrammatically the heat energy which by driving the molecules farther apart causes the water to change its condition, but not its temperature.

condition to another, there is still another element that must be taken into account—pressure. If a cubic inch of water be confined within a strong steel box holding exactly one cubic inch, and heat be applied, the water cannot become steam, but continues to grow hotter and hotter until it in all probability becomes white hot. This element of pressure is a very important factor in the various changes of condition, as we shall see later when we come to consider the liquefaction of gases.

In a mixture of water and ice, the temperature of each is the same, viz.: 32° F. What, then, is the difference between them? Simply this: the water contains heat vibrations sufficient to lessen the cohesion between its molecules, and they are permitted to move freely about through the liquid. It will be remembered that the difference between solids, liquids, and gases, is one of molecular freedom. It is necessary to heat ice to melt it. And yet the temperatures of freezing water and melting ice are precisely the same. Here we have exactly the same problem as in the case of the boiling water and steam. And as in the latter case, the heat vibrations simply give molecular freedom, but not higher temperature. When these heat vibrations are taken from water, ice is the result. Freezing is nothing more nor less than a heating

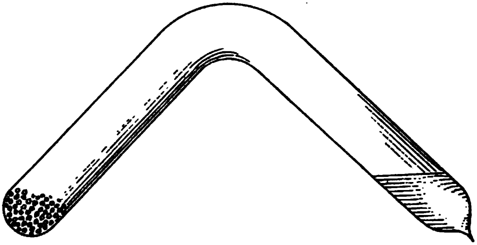


Fig. 2.—A Faraday Tube

process. In fact, this principle is taken advantage of in a practical way by farmers who protect their potatoes in cold cellars by filling tubs with water and placing them adjacent to the potato bins. The enormous amount of heat energy set free by the freezing water serves to protect the potatoes from damage.

All of this is simple and easily understood, but it took the world many thousands of years to learn the lesson. Up until about a century ago, the world had a very hazy conception as to the vibratory nature of heat, and rather considered it as a material thing, a fluid which permeated matter like water does a sponge. Aristotle, in the fourth century, B. C., taught that heat is one of the four elements that enter into the composition of the universe, the other three being water, air and earth. And this idea clung persistently in some form or other to the men who made science their pursuit, through more than a score of centuries. In 1799, Sir Humphrey Davy in a brilliant essay on Heat, heartened the few devotees of science who believed in the "motion" theory of heat, and thereby stimulated research. In 1806, Northmore succeeded in liquefying chlorine gas by compressing it to one-tenth its volume. This remarkable experiment set the world to thinking. In 1823, Faraday, the book-binder's apprentice, liquefied chlorine by heating the hydrate of that gas in a bent tube (Fig. 2), one end of which was closed, and the other end sealed after the introduction of the hydrate. The sealed end was placed in a freezing mixture, and the other end heated. Chlorine was given off in large quantities but found itself hampered by the narrow confines of the tube and was crushed by its own pressure into a liquid. With this simple device, a bent tube, Faraday succeeded in liquefying sulphur-dioxide (the gas which is given off when ordinary sulphur is burned in air), carbonic acid gas, nitrous oxide, cyanogen, hydrochloric acid, and ammonia.

A gas may be liquefied not only by compression, but

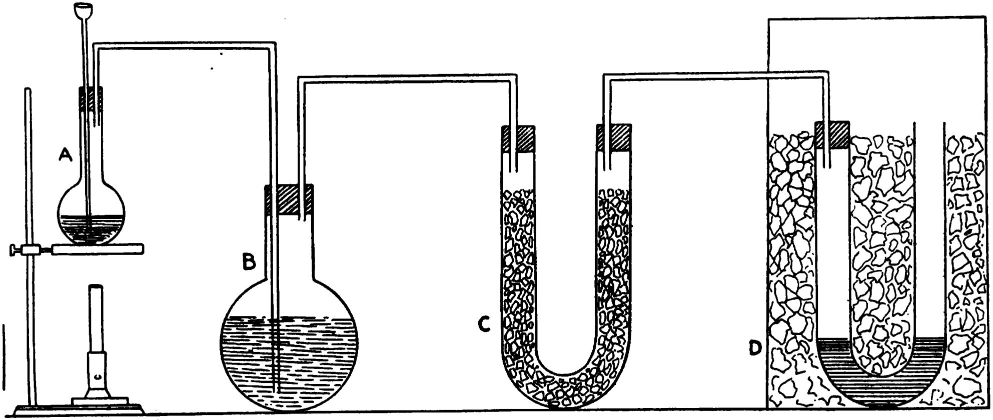
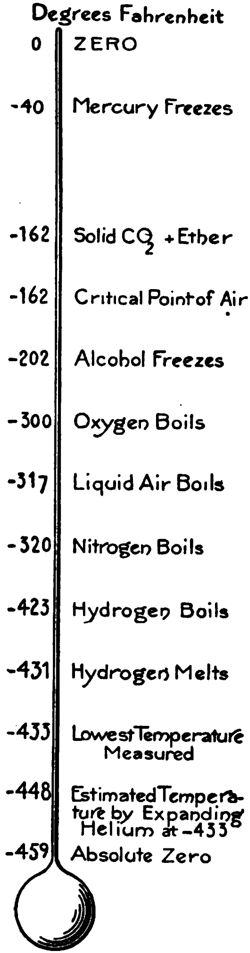


Fig. 3.—Apparatus for Liquefaction of Gases by Cold

also by extreme cold. In most cases both are required. Heat ever struggles to maintain an equilibrium, and two bodies of different temperatures placed in close contact will become equal in temperature. In Fig. 3 is shown a device whereby many gases may be liquefied on the principle of equalization of temperature. Flask A contains copper and nitric acid; B is a wash bottle containing water; C is a drying tube containing calcium chloride, while D contains a freezing mixture of pounded ice and ammonia chloride. The gas, sulphur dioxide, will condense into a liquid in D, as the freezing mixture warms itself at the expense of the heat vibrations of the gas, which is consequently reduced to a liquid.

Numerous other gases were liquefied after Faraday's brilliant work with chlorine, and it was confidently predicted that all gases would finally yield to the same method as Faraday had used. Six gases, however, obstinately refused to liquefy, and were known as "permanent gases." Even Clerk Maxwell, one of the greatest mathematicians and physicists the world has ever known, declared positively that hydrogen, at any rate, could



Low Temperature Scale

never under any circumstances be liquefied. He undertook to demonstrate this bold statement mathematically. Faraday, however, to the end of his days maintained, mathematics or no mathematics, that some day hydrogen would yield. Time has shown that Faraday was right. These six gases were laughing gas, marsh gas, carbonic oxide, nitrogen, oxygen, and hydrogen. Apparatus for applying the enormous pressure of over four tons per square inch was used in the attempt to liquefy these refractory gases, but all in vain. Science, baffled, reviewed all it had done, and decided that something besides pressure was needed to solve the problem. Then out from some dim laboratory crept the solution of the problem. And the secret that had halted the eager scientists for so long is simply this: that every gas has what is known as a "critical temperature;" that this critical temperature differs with each gas; and that all the pressure in the universe could not liquefy a gas if it were not first cooled below this critical point.

Then Science buckled on its armor and went after the "Big Six" as they were familiarly known at that time. One by one they were conquered and literally made to run like water. Even hydrogen, as will be described later, gave up the ghost, and now no gas remains that has not been liquefied. Air has been liquefied by the hogshead, and sent hundreds of miles for lecture purposes. Science has never achieved a victory greater than this. How delighted Faraday and Davy would be, were they permitted to come back to earth to view the wonderful progress made by science in this their favorite line of research!

The principle involved in the liquefaction of the so-called permanent gases is precisely the same as that indicated in the liquefaction of the other gases before mentioned. It is simply a matter of compression at the proper temperature, and then—expansion. When one breathes out used air from the lungs through the wide open mouth, the breath has the same temperature as the body, 98.6° F., and frequently, on a cold day, we warm our fingers by breathing on them. If, however, we blow the breath vigorously from the mouth, the temperature of the breath appears to be much lower than when breathed gently and with open mouth, and is decidedly cooling in its effect. This latter fact is due to the well known principle established by Lord Kelvin, that a compressed gas upon expanding will absorb heat. The breath, compressed by being forced to pass through the small orifice made by the puckered lips, immediately expands upon being admitted to the outer air, and to do so, must take up heat. This is also the identical principle involved in the manufacture of artificial ice. Ammonia gas is first compressed into a liquid, and then liberated into a network of tubes surrounding large sheet-iron boxes filled with distilled water. The liquid ammonia set free at one end of the pipe system, begins at once to evaporate and by the time it has scampered through the long iron tubes it has become a gas. As we have learned, to change a liquid to a gas requires heat. This heat is taken from the iron piping, an excellent conductor, which in turn robs the water of its heat, thus freezing it.

Another good example of the same principle is shown in the phenomenon of perspiration. The body, in order to carry on its various chemical and vital changes works at a temperature of 98.6° F. When one over-exercises, the bodily temperature rapidly rises., Immediately the sweat glands, ever on guard, pour forth their water. This water, or sweat, begins to evaporate, and in doing so, takes excess heat from the body, reducing its temperature to normal.

In the East Indies, water quite cold may be readily obtained by placing the ordinary tepid water in porous earthenware jars in a draught of air. The water oozes through the porous walls and passes off as vapor, taking the requisite amount of heat necessary for evaporation from the water within the jar, reducing its temperature considerably.

In 1893, Dewar liquefied air by means of great pressure and a "step-down" cooling process. He used first liquid ammonia or frozen carbonic oxide; then ethylin, whose freezing point is still lower, and so on, successive substances being used, each with a lower point of liquefaction than the preceding substance, until finally air itself was liquefied at a temperature of 317° F. below zero. Dewar produced only a few drops of this precious fluid, and said afterwards that a quart would cost from $2,500 to $3,000. Shortly after Dewar's brilliant achievement, Tripler of New York succeeded in making liquid air by the gallon, and at a comparatively low cost. Tripler used air itself as a medium for cooling the portion of air to be liquefied, thus cutting down the cost of Dewar's method.

The liquefaction of hydrogen by Dewar was indeed a triumph. Hydrogen, of all the gases, is the most refractory. Kelvin's law, before quoted, did not seem to apply to hydrogen, as expansion instead of cooling it, really made it warmer. By a series of exhaustive experiments, it was learned that this action was due to the fact that the hydrogen had not been cooled nor compressed sufficiently before it was allowed to expand. Dewar placed some pure hydrogen under enormous pressure, and surrounded it with intensely cold refrigerating substances; then suddenly opened the stop-cock of the vessel containing the compressed hydrogen. The gas, rushing forth, expanded immediately, and in doing so robbed the remaining gas of sufficient heat to liquefy it, and hydrogen, the last of the "permanent" gases, was conquered.

The liquefaction of hydrogen marks practically the lowest temperature so far attained by man, and the point reached is very near to the Absolute Zero (Fig. 4), where heat vibrations are unknown, and matter itself is supposed to be in a state of absolute rest.

CHAPTER III

SOME EFFECTS OF LOW TEMPERATURE UPON MATTER

WHEN Columbus in 1492 opened wide the portals of a vast domain to the restless, eager adventurers of Europe, the ocean between the old world and the new was soon alive with the sails of ships carrying intrepid souls, seeking the wonders and mysteries of an unknown land. So, likewise, has it been with the discovery of an easy entrance to the realms of extremely low temperature. Investigators by the score have gone far into the domain of cold, and it is the purpose of this article to relate some of the wonderful facts that have been discovered. It is difficult for the layman who is unacquainted with the marvels of extreme cold to appreciate the relationship that the temperature of liquid air bears to that of ordinary liquids. Boiling tin bears about the same ratio to water at 70° F., as water at 70° F. does to liquid air. A cake of ice at 32° F. is ordinarily considered to be rather a cold substance, but it is as much hotter than liquid air, as the oven in which bread is baked is hotter than the ice. A tea kettle partly filled with liquid air and placed on a cake of ice receives so much heat from the ice that the liquid air soon boils vigorously, and the boiling can be made more violent by adding a few lumps of ice. If the normal temperature of the earth were at the freezing point of air, and we could obtain a block of ice such as is distributed by the ice-man of to-day, such ice could be used as fuel, and would be put into the furnaces instead of coal. Just imagine how strange it would be for the housewife to roast beef in the Age of Cold by placing it on a lump of ice in the oven! One peculiarity of liquid air is of great importance to us We have all noticed what happens when a drop of water is spilt upon a hot stove. The water does not immediately turn to steam, but glides swiftly about on the hot iron. This is due to what is known as the spheroidal condition. A small layer of steam forms immediately under the drop of water, and acts as a cushion and is a poor conductor. The heat from the stove is prevented from acting directly upon the water, or an explosion would occur, due to the rapid formation of steam. In the case of liquid air a similar phenomenon is observed, as a cushion of air all around it acts as a non-conducting medium, which prevents the rapid change of condition. Otherwise the liquid air would act as an explosive. By reason of this spheroidal condition, the hand may be plunged for an instant into liquid air without harm. If it were to remain there, however, longer than a second or two, the hand would freeze solidly. Liquid air, poured into a tin bucket boils violently, just as water at ordinary temperature would boil if poured into a red-hot vessel. Hence, the keeping of liquid air for any considerable time is at present an impossibility. Professor Dewar devised a very ingenious arrangement (Fig. 1) by which liquid air may be retained about 30 times as long as when placed in an open vessel. It consists of two or more glass bulbs, one within the other, and separated by a vacuum. Heat travels in three different ways. By conduction: as when one heats the end of a poker, and the molecules of the iron successively take up the vibrations, and travel through the length of the poker. By convection: as when water is heated, and rises, owing to its expansion and its subsequent displacement by the heavier cold water at the top. By radiation: as when the sun shines through the windows of our homes on a cold winter's day, and carries with it some of the solar energy in the form of heat waves. Dewar's device practically eliminates the conduction of heat from the outside air, as the vacuum is a non-conductor. The access of heat by radiation is also prevented to a large extent by silvering the outer surface of the inner bulb. This silver acts as a mirror which reflects any heat that may seek entrance to the liquid air by radiation. Commercially, liquid air is shipped in large galvanized iron tanks, lined with felt, and the surface of the liquid loosely covered with some non-conducting material.

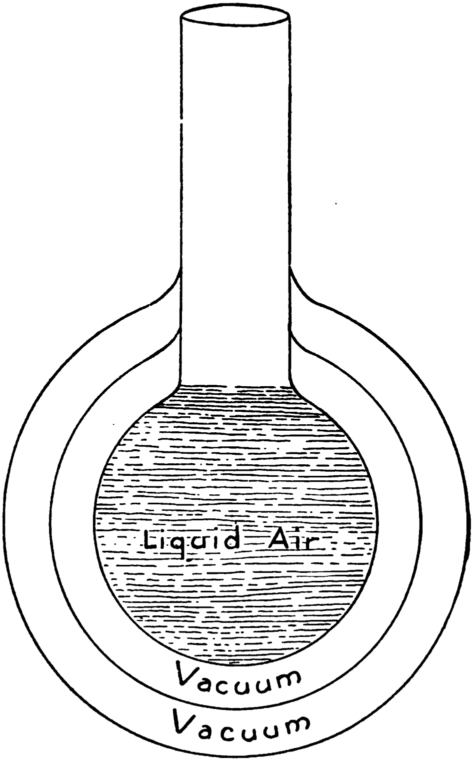


FIG 1
Dewar Bulb

That liquid air has a therapeutic value was demonstrated by an interesting experiment performed in Paris. Professor Pictet, one of the pioneers in low temperature experiments, built what might be termed a "frigorific well," 6 ft. deep and 2 ft. wide, lined with heavy furs. He surrounded this well on all sides with liquid air, and obtained a temperature of about 166 degrees below the Fahrenheit zero. He descended into this cold well and remained eight minutes. The temperature of his body rose slightly, due to the increased activity caused by the rapid oxidation, as the body in order to keep its temperature at normal was compelled to literally burn up its available fuel. This oxidation produced a ravenous appetite, and Pictet claims that after his ascent from the well he enjoyed a meal for the first time in many years. By continuing the use of intense cold for several weeks, he cured himself of dyspepsia that had been chronic. Physicians also claim that the intense cold produced by the application of liquid air is also a specific for some forms of cancerous growths, as it cuts off the blood circulation in the morbid parts; this circulation may afterwards be prevented from renewing itself.

The effect of liquid air upon metals is remarkable. A spiral of soft solder which may be readily elongated by pulling with the fingers, becomes as steel, when bathed in liquid air, and has the temper and elasticity of a clock spring. Tin becomes almost as brittle as glass. Tuning forks of steel rise perceptibly in pitch. The breaking

Table showing breaking stress of metallic wires in pounds. Diameter of wire .098 in. (Dewar).

	Temperature	
Material	**59° F.**	**295° F.**
Steel (Soft)	420	700
Iron	320	670
Copper	200	300
Brass	310	440
German Silver	476	606
Gold	255	340
Silver	330	420

point of steel, as shown in the table on the preceding page, is practically double, and the same effect is observed upon other metals and alloys.

Metals become almost perfect conductors of electricity when cooled to the temperature of liquid air. Could this fluid be applied economically in a jacket surrounding the copper conductors which serve as transmitting agents for the immense output of electrical energy from the great dynamos at Niagara, the thinnest kind of wire would be ample, displacing the great conductors now in use, and thereby saving enormously in the cost of installation in copper and other items.

One peculiar fact that has always bothered physicists and chemists has been definitely settled through the agency of low temperatures now so readily reached. Hydrogen gas in many respects is very like a metal, and it was confidently asserted by some theorists that if it were ever liquefied, it would resemble mercury. It was found, however, that liquid hydrogen is not in the least degree of a metallic nature, and is an absolute non-conductor of electricity. Owing to its extreme lightness, hydrogen is used in balloons. The production of the enormous quantity of this gas required for an ordinary balloon necessitates quite an outfit, and it is therefore practically impossible to add more hydrogen to the always collapsing balloon without a return to the garage. Liquid hydrogen, however, has settled this difficulty in a very satisfactory way. The aeronaut can easily carry with him a large quantity of liquefied hydrogen, as it weighs only one-fifteenth of an equal bulk of water, and, upon evaporation, will produce 800 times its volume in gas. It can be carried instead of sand for ballast and has this great advantage: when sand is dropped, the buoyancy of the balloon is increased only by the weight of the sand; while in the case of liquid hydrogen upon its expansion to the gaseous form all the lifting power of the hydrogen thus added is gained.

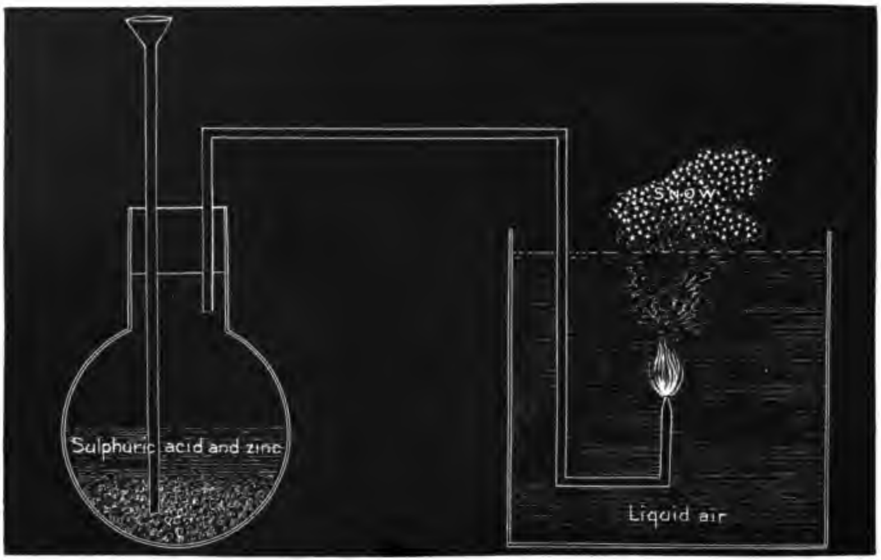


FIG. 2

Burning Hydrogen in Liquid Air, Snow Being the Product of Combustion

A curious experiment is illustrated in Fig. 2. A jet of hydrogen burns readily in liquid air, and the "smoke," the product of combustion, is snow. Surely we are confronted with a marvelous paradox, when we note the presence in the same small vessel, of such extremes of temperature as that of burning hydrogen and liquid air, and of a flame burning brightly in the midst of a liquid, with snow given off as smoke!

If liquid air be partly frozen, until it is of the consistency of slush, and a strong bar magnet be held over it, the solid oxygen, which has a beautiful blue color and is strongly magnetic, will be withdrawn, leaving the nitrogen like a jelly in the vessel.

The color phenomena observed at low temperatures is quite puzzling to physicists. Some substances, ordinarily red, become yellow, and yellow substances, white. An egg or a bit of paraffin, when cooled to a very low temperature and then exposed to the rays of a powerful arc light, will glow with a wonderful phosphorescence, when viewed in a dark room. The egg will radiate a peculiar, wavering blue light. Other substances, such as horn, leather, glycerine, paper, ivory and rubber, become distinctly luminous. Milk, for example, becomes positively brilliant, and impure water glows more brightly than that which is perfectly pure. Whence is this light, so contrary to the canons of science? The tiny waves which produce the impression of light upon the retina, are much shorter than those that produce heat. When very high temperatures are produced, as in the boiling of steel, the heat waves are always associated with much shorter waves which give rise to the well known luminous phenomena to be observed in a Bessemer converter. No one, however, would think of obtaining light from an iron rod heated even to 400° F., as the ether waves set up by the heat vibrations are much too long to produce light. And yet, at a temperature almost a thousand degrees below that point, and where the heat waves are longer instead of shorter, many substances glow with a strange, mysterious light. As Professor Dewar has pointed out, the molecules of matter at low temperatures seem to have greatly increased powers of absorption. At any rate, this one fact is demonstrated, that at low temperatures, light is given off with the minimum of heat. Only about five per cent of the total energy supplied to an incandescent electric bulb is available as light. The ordinary carbon-filament lamp represents just as much waste of energy as a pianist does who forces down every key in the keyboard of his instrument when he wants to strike middle C alone. It is quite probable that this strange phenomenon of light at low temperature is one of the guide posts pointing out the way to the goal so eagerly sought by physicists and chemists,—light without heat.

Through the strange alteration in the properties of matter produced by extreme cold, chemical activity is almost destroyed. If a bottle filled with a mixture of chlorine and hydrogen be exposed for an instant to the action of sunlight, the intense chemical attraction existing between the two gases will cause them to unite instantly with explosive violence. At the temperature of liquid air, however, these two substances will lie quietly side by side, without exhibiting the slightest tendency to combine.

Coal gas loses to a large extent its luminous qualities when cooled to the temperature of liquid air. Rubber becomes like glass. Flowers, meat of different kinds. and eggs, become brittle, while the peculiar condition of matter known as magnetism is wonderfully increased.

It is possible to obtain a practically perfect vacuum by means of liquid air. Air is first frozen in a sealed glass tube by means of liquid hydrogen. After the air has solidified, the upper part of the tube is sealed off in a blow-pipe flame, and a vacuum is obtained that can be secured in no other way.

As a means of purification, liquid air is of great value. Freezing is a purifying process. Ice is always purer than the water from which it is formed. By taking advantage of this principle, the chemist is able to crystallize to a high degree of purity, many of the chemicals used by man. Chloroform, however, whose purity is of greatest concern to the physician, has a very low freezing point and cannot be purified in the ordinary way by crystallization. Now, however, it may be frozen quite easily by means of liquid air, and the solid crystals of chloroform, absolutely pure, may be removed from the mixture and melted. Other liquids similar to chloroform may be purified in a like manner.

A great deal of nonsense has been written about liquid air as a source of power. Ten years ago mushroom companies were formed throughout the length and breadth of the land to exploit this wonderful source of energy. Like mushrooms they vanished. A foot-pound of energy when applied through a machine of any kind will give a foot-pound of work in return, less the friction loss. It is impossible to get something for nothing even in the world of mechanics. While liquid air does give enormous pressure when confined, and can be made to run engines and do other work, the same elementary law quoted above, still obtains. Air must be liquefied before it will do work as liquefied air, and the liquefaction costs more in work units than are available from it afterwards.

* * *

CHAPTER IV

THE PRODUCTION AND USES OF HIGH TEMPERATURE

THE most remarkable and the most valuable discovery ever made by man is that of fire. Prior to that epoch-making gift from the gods, man was brother to the brute, and his splendid possibilities were embryonic. With the coming of fire, came all the wonderful development that has enabled man to assert and defend his claim as the lord of creation.

Fire has done more for civilization than all the armies, libraries and treasures of antiquity. It has been only within comparatively recent years, however, that man has been able to harness the steed of high temperature to the wheels of progress. Before that time he was unable to go much further than 3000° F., and all the magic properties of fire at temperatures up to 7000° F. were unknown to him. Now he is able to command substances hitherto infusible, to melt, and to make combinations unheard of outside of the tremendously hot furnaces known as volcanoes.

We are now able to emulate the volcano, so far as heat is concerned, in our laboratories, and we are even possessed of the almost magical power of welding steel rails right in the street where they lie. The apparatus and contrivances by which these wonders are produced are simple—so simple that it is a marvel indeed, that man has permitted five score of centuries to go by, before he made up his mind to use them.

Some carbon compound, such as wood or oil, has been used from time immemorial for the production of heat. With the development of chemistry, man has learned the exact nature of the combinations necessary to the scientific and economic output of caloric energy. For example, he understands the importance of an abundant supply of the element oxygen, and the Bunsen burner typifies his advance in this respect. A little over a century ago, the discovery was made that air itself, or rather its oxygen, was just as important in the production of heat as carbon and hydrogen. Air contains about 21 parts of oxygen and 79 parts of nitrogen. When the proportion of air supplied to the flame is artificially increased, as in the case of the Bunsen burner (Fig. 1), the heat thus obtained is far beyond that produced by the burning of illuminating gas alone. It is this richer mixture that renders possible the excellent and cheap light produced by the glowing of the oxides of thorium and cerium in the ordinary incandescent mantle, so common in our households.

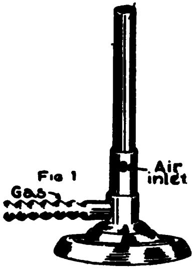


Fig 1

The Bunsen Burner

Instead of using more air, as in the case of the Bunsen burner, man has tried the effect of using pure oxygen itself in combination with hydrogen, and the exceedingly hot flame of the oxy-hydrogen blowpipe (Fig. 2), is the result. This flame is so hot that the ordinary metals such as lead, tin, zinc, iron and even platinum will melt in it quite readily. A novel and profitable industry has sprung up in Paris, that of the manufacture of artificial rubies. A ruby, after all, in spite of its exaggerated value, is not such a wonderful thing, if we consider its composition alone. It is just plain, ordinary clay, containing a trace of chromium. This clay, however, differs from ordinary mud in that it is crystallized. Figure 3 shows diagrammatically the simple apparatus which transforms a few grains of worthless clay into a genuine ruby.

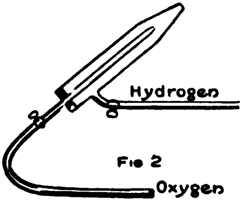


Fig 2

The Oxy-Hydrogen Blowpipe

At the top of the furnace shown in the diagram, a little calcined alum, mixed with the right percentage of chromium-oxide to give it the true ruby color, is placed on a fine sieve, which is gently tapped at regular intervals by an appliance operated by an electro-magnet. This causes the powder to sift down through the oxygen gas where it finally meets the hot zone made by the combination of the two gases hydrogen and oxygen. The temperature of this zone varies from 3300° F. to 3600° F. The powder fuses and drops into the platinum receptacle, and as each drop falls, it unites with the others in the dish, thus forming a pear-shaped ruby resting on its stem. Each blowpipe has an output of about eight to ten carats per hour, and a single operator can attend to a dozen blowpipes. Rubies weighing 80 carats can thus be built up. These rubies, after they have cooled, are split lengthwise. They are cut and polished, the final polishing being done with tripoli and water. The cut gems ready for the market are worth about 40 cents a carat.

This price is insignificant as compared with that of the natural Burmah ruby, whose market value is almost fabulous. Chemically, optically and physically the "scientific" rubies are identically the same as the natural stones. Even in both forms, the slight microscopic air bubbles called "frogs" or "inclusions" are present. Lacroix, the eminent geologist and mineralogist, asserts that the artificial ruby cannot be distinguished from the natural, while Pinier, a leading gem expert of Paris, claims that they can readily be distinguished. At any rate, the pawn brokers of Paris have placed rubies under the ban, and it is almost impossible to secure loans when rubies of any description are offered as security.

Fire is the great natural purifier of metals, and we are learning more and more about its use and misuse in the industrial world. We have been a long time learning. Thousands of years ago fire was used in the reduction of metals from ores, and the Bible contains many references to metallurgical operations. We are told that the finer sat before his melting pot and when he saw his face reflected in the beautifully clear mirror of silver, he knew his task was finished. Many references are made to the refining of gold, and Job tells us of the "brass that was molten out of stone."

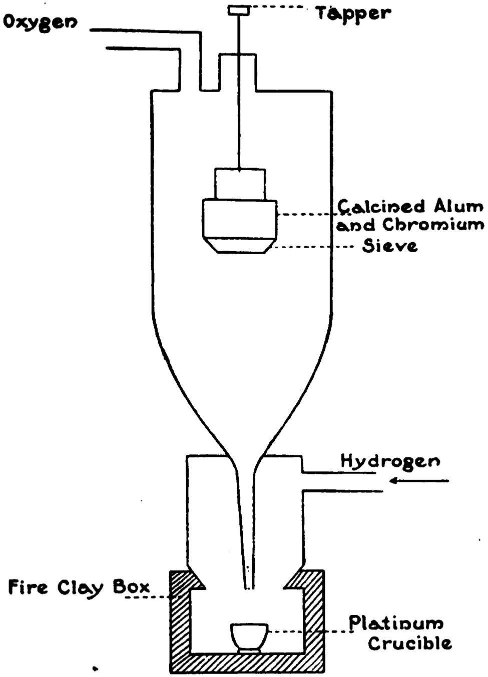


Fig. 3
Ruby Furnace

Fire is a good servant but a bad master. That curious substance called steel is an example of this fact. Too much fire is as bad as not enough, and sharp-eyed chemists pounce upon a sample from every melt to learn just what the fire has done, and to decide whether the product of the converter shall be made into razor blades or ploughshares. Just a little more or less of that queer element known as carbon and the entire nature of the steel is changed. The late Sir William Austen-Roberts in an address before the students of the Royal School of Mines, said: "If the thousands of tons of steel in the Forth bridge had contained two-tenths less of carbon, the material would have been worthless. Thousands of tons of copper would be useless if it contained a trace of bismuth, and the eighty millions sterling of gold coin in circulation would have crumbled away if it had contained one per cent of lead."

Boiling steel, whose temperature is in the neighborhood of 3500° F. is rather hot, but a temperature far beyond that may readily be obtained by the use of the new compound known to science as Thermit. This substance is easily made and consists of a mixture of iron oxide and finely granulated aluminum. If this compound be mixed with a little magnesium and barium-dioxide to supply the necessary heat to start the combustion, or simpler still, if an ordinary storm match be thrown into it, the aluminum and oxygen will unite with frightful energy, and the consequent evolution of an enormous amount of heat.

Almost instantly the temperature of the oxide of aluminum and pure iron thus formed rises to about 5500° F. The explanation is simple. Aluminum and oxygen are exceedingly fond of each other in a chemical sense, and it is an extremely difficult matter to break up ordinary clay, a combination of aluminum and oxygen, into the elemental substances, so intense is the chemical affinity which holds them together. Only a very high temperature can do this. Conversely then, when we place the elemental substances aluminum and oxygen in such circumstances that they will readily combine, the same amount of energy that would afterwards be required to separate these two allies, will be set free, and will appear as the lowest form of energy—heat. We see the same principle illustrated when we turn water at the boiling point into steam at the same temperature. An enormous amount of heat energy is required to change water at 212° F. into steam at 212° F. Conversely, when steam is permitted to change back into water, this heat energy is given off, although both the steam and water are just 212° F. In other words, whether the special form of energy be known as heat, light, magnetism, or gravitation, one form may readily, under the proper conditions, change into the other, and the lowest form is always heat. Thermit is invaluable where a very high temperature is needed in spots, as in the repair of broken shafts, castings, the welding of iron, and the making of continuous rails. It is also invaluable in the production of certain metals, such as vanadium and chromium, so essential to the manufacture of special steels. If instead of iron oxide, we use vanadium oxide, or chromium oxide, the aluminum reduces the oxygen and sets free the pure vanadium or chromium.

The next step-up in temperature is produced by the electric furnace. In this wonderfully simple contrivance, the highest temperatures known to man are easily produced. Again do we meet with the principle that energy may readily be transformed from one form to another, the lowest step being heat. A current of electricity flowing through a wire meets with resistance. In some unknown way, the copper or carbon, although commonly known as good conductors, present some molecular difficulty to the passage of the electricity, and the electrical energy is transformed into heat. The glowing filament of the ordinary incandescent electric lamp is evidence of this. If the current be heavy, and the circuit wires where the gap is made be tipped with carbon, the electrical energy will jump across the gap, overcoming the enormous resistance thereby put into the circuit. This resistance results in the transformation of the electrical energy into heat and light. This is shown in the ordinary arc lamp now used so commonly in the illumination of our highways.

An electric furnace is simply a gigantic arc lamp, whose temperature is from 6000° F. to 7000° F. Into this enormously hot zone (Fig. 4) various substances are placed, and its effect upon hitherto infusible compounds is little less than magical. Coke, clay, sand, carbon, which have hitherto been unmastered by man, are broken to his bridle and become willing draught horses, which do his bidding in the host of industrial uses to which they may be put. Quicklime and coke are readily converted into calcium carbide, that valuable substance which upon the addition of water forms the powerful illuminant, acetylene.

Coke and sand, when fused in the electric furnace, give us carborundum used so much as a polisher and abrasive. The electric furnace is also used in the manufacture of aluminum, carbon-disulphide, artificial graphite, phosphorus and many other substances of great value to man. It has only been a few years since Moisson astonished the world by the manufacture of genuine diamonds. These diamonds, it is true, are of microscopical size, but the fact remains that they are genuine diamonds. Moisson placed some pure carbon in an iron cylinder (Fig. 5) and then immersed the cylinder in a mass of boiling iron.

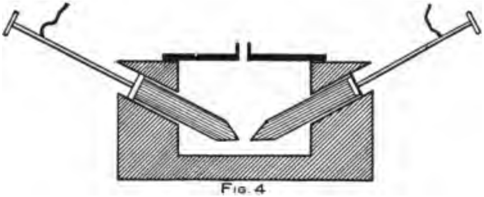


FIG. 4

The Cowles Type of Electric Furnace

Since molten iron absorbs carbon like water dissolves salt, the cylinder became completely saturated with carbon. Then he plunged the whole fiery mass into ice cold water. The enormous pressure produced by the contraction of the outer mass of the iron upon the uncooled interior caused the dissolved carbon to separate into tiny crystals—real diamonds. Some day, possibly, we shall learn how to do the same thing that Moisson did, except that we shall use two or three hundred pounds of metal instead of a few ounces, and possibly, who knows, we may be able to supply diamonds in commercial sizes, even as we are now able to satisfy our taste for rubies, at a price within the reach of all.

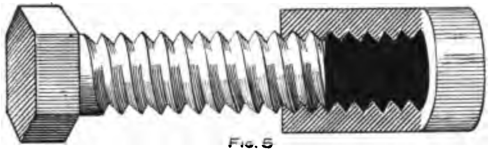


Fig. 5

Moisson's Iron Cylinder for the Manufacture of Diamonds

CHAPTER V

HIGH TEMPERATURES AND THE RARE METALS

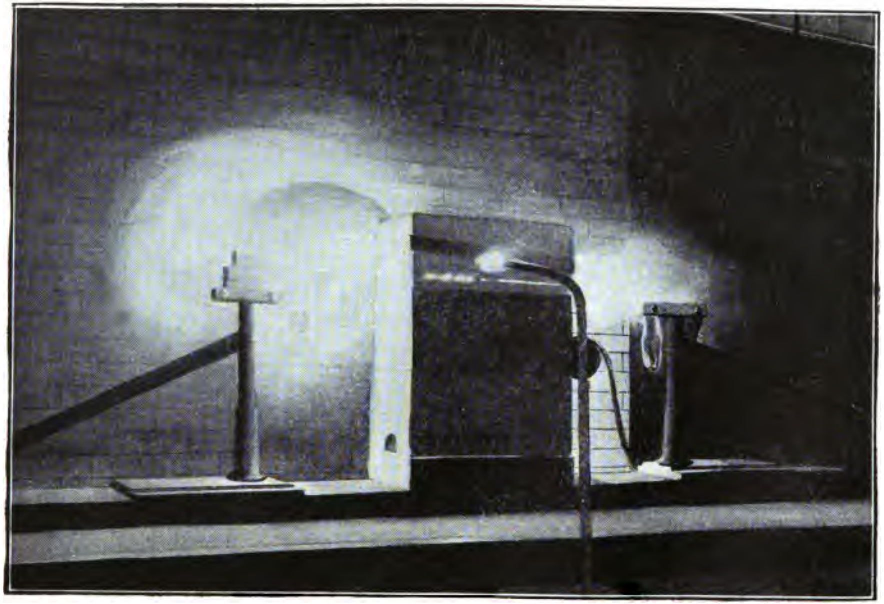
FOR thousands of years the world jogged along with only four metals—copper, tin, gold and silver. Today we have 59, and are still adding to the list. Even iron, the metal which forms the basis of our modern civilization, was unknown for scores of centuries, and was impressed into the service of man 1,000 or 1,500 years before the Christian era. Lead and mercury were next added to the list, and then the world, tired out with its metallurgical exertions, rested comfortably for many centuries with these seven metals. During the middle ages, antimony, bismuth, zinc and arsenic were discovered, more by accident than by systematic research. This inactivity was partly due to the lack of facilities on the part of the few earnest seekers after scientific truth, and partly to the charlatanism and jugglery of fakirs and frauds of the time, who were seeking such impossibilities as the elixir of life, and the philosopher's stone—which would transmute the so-called base metals, like copper or lead, into gold.

Within the last two hundred years, about 50 metals have been discovered. Most of them, it is true, have been looked upon by the world as curiosities, and they have been relegated to the dusty shelves of chemical museums in tiny little vials, as concrete samples of the wonderful achievements of modern chemical research. Occasionally they would be referred to by some writer gifted with a vivid imagination, who would call to mind their extreme rarity and their fabulous value—but only as chemical curiosities and never as substances that would be of use to mankind. Then the little vials would be put back on the shelves, out of sight, out of mind, until the public again wished to hear the dreams of gallium, aluminum, germanium and tungsten, and to estimate what it would cost to make a pound of these rarities.

With the advent of the electric furnace and the use of temperatures hitherto unheard of, these little vials have been taken down from the dusty shelves. One by one the rare metallic oxides have been introduced to the fearful heat of the flaming arc and reduced to the form of pure metals; and these rare metals, now rare no longer on account of the cheapness of reduction and the abundance of ore, are taking their places in the sphere of industrial activity. The little, dust-covered vials are looming up, and keen, hard-headed scientists are studying them with a view to their possibilities and the best means as to their utilization.

Take aluminum for example. In 1888, aluminum first appeared on the market and sold for five dollars a pound. It was still a curiosity, and here and there, some one would get hold of an ounce or two and muse over its extreme lightness, its beautiful color and its oxygen resisting qualities. But still a rarity on account of its prohibitive price. Then comes the electric furnace with its extraordinary high temperatures. Aluminum immediately drops from five dollars a pound to less than 35 cents a pound, and the world sits up very straight and takes notice. A metal more useful than gold or silver—possibly than iron, has joined the great procession of modern business opportunities, and immediately the business man seeks the man of science and talks about "output and possibilities."

Aluminum has had a remarkable growth, commercially, but the next few decades will show its real value and use. It is popularly supposed that iron is the most abundant of all the metals, but analyses of the earth's crust show that aluminum is the king of all the metals so far as quantity is concerned. There is just a little more than eight per cent of aluminum in the crust of the earth, or almost twice as much as there is of iron, and more than



Electric Furnace for Reduction of Rare Metals

80 times as much aluminum as there is of copper. Some time aluminum will be made for a few cents a pound, and it will eventually displace iron in many places where iron is now considered to be indispensable. It is about one-third the weight of iron, is about as strong in tensile strength as cast iron, and just as soon as the proper alloy of aluminum can be found, it will be steel's strongest rival. At present, metallurgists are handicapped by the fact that aluminum can be made from only one ore, bauxite, and this ore is found in but few places and is rapidly being exhausted. There is no doubt, however, that in a short time we shall know how to extract the aluminum from ordinary clay, economically. Then every clay bank will be a mine of high-grade ore, clay containing a high percentage of aluminum; every bit of slate will yield to the magic caress of high temperature its precious prisoner of pure aluminum, which it has so jealously guarded for untold ages. Iron, with its rusting, its crystallization and its strange behavior as shown in the form of steel, will be displaced by its peerless young rival, aluminum.

Ever since Edison, over 25 years ago, discovered the incandescent electric lamp, there has been an eager search for a substance that would take the place of the tiny thread of carbon which forms the filament of the lamp. Almost every substance under the sun, from bamboo to silk, has been tried for this purpose, but the same objection applied to all. Every one would rapidly deteriorate or blacken the bulb, and the longer they were used the more electricity they would convert into useless heat, and the less light they would give. In fact, 98 per cent of the total electric energy was wasted in heat, while only two per cent was available as light. There is even more waste energy in the ordinary carbon-filament electric lamp than there is in the ordinary steam engine. Numerous attempts to substitute metal filaments for the carbon were made, but it was impossible to find a metal which would not melt far below the temperature at which the light vibrations were available. With the coming of the electric furnace, the difficulty was solved. The rare element, tantalum—so-called from Tantalus, as it was so elusive and hard to get hold of in its purity—was conquered by the high temperature of the modern electric furnace and has found extensive use as a substitute for carbon in the manufacture of filaments. Tantalum, owing to its high melting point, between 5200° F. and 5300° F., is a very satisfactory substitute for carbon. It gives much more light and uses only two watts per candlepower, while the carbon filament uses three and one-half watts. Another use for tantalum depends upon the fact that it is very hard. Various attempts have been made to drill through a sheet of this metal; a diamond drill running at the rate of 5,000 revolutions per minute resulted in a penetration of only a small fraction of an inch, although the boring was kept up continuously for three days, and the sheet of tantalum was only a third of an inch in thickness. No doubt this highly refractory metal will eventually be used for bearings and dies and drills, or for any other purpose where extreme hardness is desired. Fortunately we have abundant supplies of this valuable substance in South Dakota and North Carolina.

It is a curious fact that the candlepower of an incandescent electric lamp increases out of all proportion to the increase, slight though it may be, in the temperature of the filament. Taking advantage of this fact, tungsten, another product of high temperatures, is now used quite extensively in the manufacture of filaments. Tungsten has a melting point of 5500° F., only a few hundred degrees higher than tantalum, and yet this comparatively slight increase is sufficient to double the candlepower and at the same time to lessen the expenditure of electrical energy. A tungsten lamp uses only one-third the energy necessary for a carbon filament and gives far greater candlepower. It is true that the first cost of a tungsten lamp is almost prohibitive, but that is now. Wait until the magic work of the high temperature furnace is completed, and we are able to obtain the element cheaply. Then a carbon filament lamp will be found only on the before mentioned dusty shelves of museums as a curiosity.

Large quantities of tungsten ore have been found in Montana and California, and there is no lack of raw material for the future development of this industry. This important metal has other possibilities than the one indicated and is employed in fire-proofing cloth for curtains, and is invaluable in its use in dyeing, being a powerful mordant. A mordant is a substance that forms an insoluble compound with a coloring matter and holds it within the tissues of the fabric.

Cerium and thorium are rare metals and were until recently regarded as curiosities of little practical value. Now they are looked upon literally in an entirely new light as they form the basis of the chemicals used in impregnating the meshes of the ordinary gas mantle, so common now as an illuminant in our homes. And these rare metals have been the saving of the coal gas industry, as their radiant, powerful and cheap light enables gas to compete with electricity as a means of illumination.

Chromium, whose melting point is beyond that of platinum, is another rare metal that has done marvelous things in the way of bettering steel. By the addition of a slight percentage of chromium, steel is wonderfully improved.

Molybdenum and uranium are also of high value for the betterment of steel, and the future alone can reveal the possibilities that lie in this direction.

And now comes vanadium, the most wonderful of the rare metals and the latest gift of high temperatures to man. Vanadium, known to the world for about 80 years, was little more than a chemical curiosity until quite recently. Then some wise experimenter added a mite of it to steel and found that its effect was almost marvelous, wonderfully improving the quality of the steel. It increases the tensile strength of the steel about twofold, and at the same time acts as a scavenger and rids it of the deleterious nitrogen and certain obscure oxides. Vanadium steel is not only statically stronger, but dynamically stronger than ordinary steel. In other words, it will not only carry greater loads, but will also withstand harder shocks.

A bar of steel of high tensile strength would make a poor axle for an automobile if it could be fractured by a sudden stress produced by a jar against a cobblestone. The steel made with vanadium and chromium seems to be less liable to what is commonly known as "crystallization," or more properly speaking, the molecular disintegration which in some mysterious way changes fine steel into a substance but little better than cheap pot-metal. It has been recently reported that vanadium steel has been made in the form of wire possessing the unheard-of tensile strength of 400,000 lb. to the square inch! Another remarkable quality possessed by vanadium is that of self-lubrication, an immense advantage in the case of high-speed tools. Enormous deposits of vanadium have been located in this country and in many other countries of the globe. Owing to the fact that certain salts of vanadium are unstable and set free pure oxygen, these salts have been used medicinally in the treatment of pneumonia, and of other diseases requiring free oxygen.

As yet we are in the infancy of high-temperature developments. There are many other little vials on the dust-laden shelves, and one by one each shall be taken down and made to reveal its secret to the busy, inquisitive chemist and physicist; and within the next twenty-five years, no doubt, marvels more stupendous than those of the past score of years will add to the comfort and wealth of mankind.

CHAPTER VI

HOW HEAT TRAVELS

THE fact that heat does travel is familiar to everyone. Whether it is demonstrated to us in a forcible manner as when we attempt to stir a fire with a poker that has been allowed to remain a few minutes in the red hot coals, or whether it is through the warming influence of the sun, millions of miles away, we know that somehow or other, heat energy has the power of traveling from place to place. Sharp-eyed, deft-handed experimenters have not only established this truth in a scientific manner, but they have also added many interesting and valuable facts to the world's store-house of knowledge. It is the purpose of this article to make clear some of these phenomena of heat which are met with daily, but are not commonly understood.

Ordinarily speaking, heat travels in three different ways: conduction, as in the case of the poker above mentioned; radiation, as when it travels from the sun to the earth; and convection, which will be explained later.

As has been shown in a previous chapter, heat is simply a form of vibratory energy. The tiny molecules which make up matter are never at rest, but are forever swaying backwards and forwards, up and down, in every conceivable direction. If this motion be increased and the molecules move through wider arcs, we say that the body has become hotter. If the motion could be absolutely stilled, then the temperature of the body would be zero —absolute zero—459° below the Fahrenheit zero. Heat is the lowest form of energy, *and eventually all matter in the universe will have precisely the same temperature.*

If this fact be true, it implies that heat must travel— not only from molecule to molecule, but from mass to mass, from earth to earth, and from sun to sun. Space is the clearing house of the universe for energy, and its emissaries and agents have been busily engaged in squaring accounts from the beginning of time, and will continue their almost endless transformations for eternities yet to come.

Conduction, the transfer of heat from molecule to molecule, is possibly the most readily understood of the three modes of travel. A molecule is made to sway in a wider arc. This increased motion is passed along to the next molecule, and then to the next, and so on until all are swaying harmoniously.

Some molecules, however, take kindlier to an increase in their velocity than others. In Fig. 1 are shown a bar of copper and a bar of iron, with little metal balls attached to them by wax at equal intervals from where the spirit lamp heats the junction of the two elements. The balls will drop from the copper bar faster than they will from the iron. We are therefore justified in stating that copper is a better conductor than iron, although just why the copper molecule takes up the energy of motion more readily than the iron, we do not know. It is on a par with many other curious facts in nature, the reason for which is unknown, and we are prone to pass it over with the familiar remark, "it is the nature of the thing."

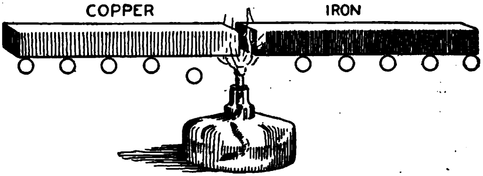


FIG. I

Spirit Heat Lamp and Bars of Copper and Iron

Silver and German silver furnish us with a still more striking example of this variation in the conductivity of metals. Heat will pass through silver with the least possible resistance, while German silver furnishes an almost impassable barrier to the transfer of heat energy, the relative conductivity being about 14 to 1. Some day, possibly, we shall understand the reason why, and electricity will be the key to the mystery, as it is quite likely that, after all, heat is but a form of electricity, whatever that mysterious fluid or condition is; or else heat and electricity are only forms of some other unknown force. It is as hard for electricity to force its way through German silver, as it is for heat, giving us a very broad hint as to the relationship existing between those two mysterious employes, so commonly used in our service.

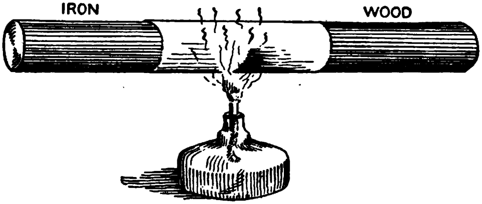


FIG. 2
Experiment in Heat Transmission

A very striking experiment (See Fig. 2) illustrating the difference in the power of substances to transmit heat may be shown by heating a paper-covered cylinder, one half of which is iron and the other half wood. The paper on the wood half will char, while the other part over the iron will be unaffected by the heat, as the iron immediately conducts the heat from the paper, while the wood is unable to do so. Water may be boiled in a paper crucible, if care is taken to have the paper smooth and free from wrinkles, as the temperature cannot rise above the boiling point of water, which is not sufficient to burn the paper.

Figures 3 and 4 are illustrations of the practical use to which the high conductivity of iron is put. In order to produce combustion, three things are essential: something to burn, something to support combustion, and a sufficient temperature. The gas above the wire screen is burning, the gas below is not. The reason for this curious state of affairs is simple. The fine mesh of iron wire which forms the screen is really made up of small iron tubes. The burning gas in attempting to pass through these tubes into the unignited gas below, loses some of its temperature by the rapid conduction of heat by the iron; hence one of the conditions for combustion, a sufficient temperature, is lacking, and the gas below will not ignite. If a flame be entirely enclosed in a fine, metallic mesh, a Davy safety lamp (Fig. 4) is the result. It is hardly necessary to call to mind the inestimable value of this simple bit of apparatus, as it has probably saved more lives than any other safety device ever invented by man.

It is an interesting and important fact to mill owners and all others who use boilers, that the scale which accumulates on the interior of boilers is a very poor conductor of heat, and while the scale prevents the loss of heat from the enclosed water and steam, it also prevents to a large extent the access of heat from the fire to the boiler. Soot or grease on a boiler are also antagonistic to the economic use of fuel, and an untidy fireman is an expensive workman. It has been estimated that one-tenth inch of scale, and one-hundredth inch of soot or grease are the equivalent of ten inches of metal. In other words, it is just as easy for heat to pass through ten inches of iron as it is to pass through one-tenth inch of scale or one-hundredth inch of soot.

Metals are by far the best conductors of heat, and silver heads the list. A good conductor always feels colder to the touch than a poor conductor. A good illustration of this is afforded when we step with bare feet from carpet to linoleum. Both substances may have the same temperature, but the linoleum conducts the heat more rapidly from the body, and hence feels colder. Liquids are extremely poor conductors. Water, for example, may be at the boiling temperature at its surface, and at the freezing point a few inches below. Gases are even poorer conductors than liquids. It is exceedingly difficult to prove that dry air has any conducting power at all. This inability of air to conduct heat is a blessing in disguise, as it is largely due to the presence of air between the meshes and fibers of our clothing that we are able to keep warm in winter and cool in summer. The air space between the walls of a refrigerator acts in the same manner and keeps down the insistent demands of the ice-man.

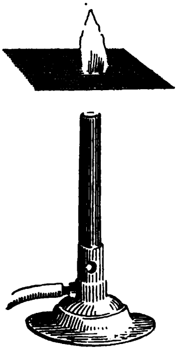


Fig. 3
Experiment

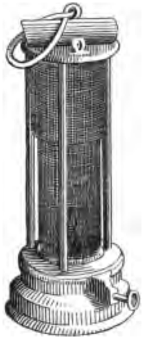


Fig. 4
Davy Safety Lamp

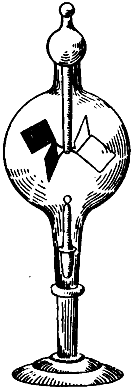


Fig. 5
Radiometer

Radiation seems to be a favorite mode of heat travel, as by far the greatest amount of heat transference is done by this means. To understand what radiation really means we must know something about light. Light and radiant heat are so closely allied that it is difficult sometimes to make a distinction between them. They travel together with the same velocity, about 186,000 miles per second. Both can be reflected and refracted, and both cast "shadows." It might seem strange to speak of heat shadows, but anyone knows that the shady side of a street is cooler than the sunny side, and the buildings which shut off the direct sunlight, do the same for the radiant heat which accompany it. The vibrations of the ether which constitute radiant heat, are a little longer than those of light and are not hot in the sense that they have a temperature comparable to the medium through which they pass. For example, the temperature of space is probably close to the absolute zero, and yet practically all the heat on the earth's surface comes from the sun through the intensely cold ether of space, a journey of ninety-three million miles, without heating it in the slightest degree. If it were "hot," it would part with its heat long before it reaches the earth in accord with the well-known fundamental principle that all bodies either give or take heat until they are equalized. Radiant heat might be likened to money. A dollar cannot be used as an article of food, but it can be transformed through the agency of a baker into good, substantial bread. Radiant heat is only a form of energy payable upon demand in what is known as "sensible" heat.

Everyone has seen the apparatus known as a radiometer, Fig. 5. The tiny little vanes, whirling around without any visible cause, have always been a source of interest, if not of wonder, to the wayfarers who chance to pass a shop-window where these delicate instruments are displayed. The little globe is almost an absolute vacuum, and the radiant heat readily crosses the vacuum and strikes the little vanes of mica or aluminum. It will be noticed that one side of each vane is black, the other is bright and shining. The radiant energy is absorbed by the black side and reflected by the other. A "kick" is thus set up by this unequal action, much the same as that which is given to a boat when one jumps from it to the shore. A radiometer has therefore two important uses, and should not be considered a toy. It demonstrates the fact that radiant energy will traverse a vacuum, and is also a good example of the law that action and reaction are equal and opposite in direction. Radiant heat meets with some trouble in passing through glass, and after it has made the journey, as through the windows of a greenhouse, the longer waves are unable to escape, and hence are put to work by the gardener in raising the temperature of his domain.

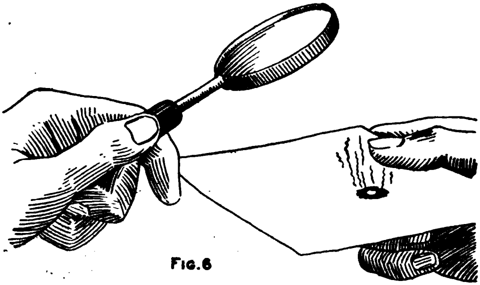


FIG. 6

Charring of Paper by Means of a "Burning Glass"

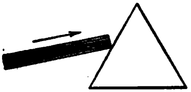


FIG. 7

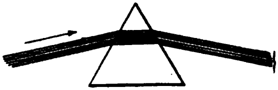


FIG. 8

Fig. 7—Rays of radiant heat approaching glass prism, which is much denser than air. The first rays entering prism are hindered, while the rays still in air are moving with the original velocity. This produces a bending of the rays.

Fig. 8—Full effect of prism on rays of heat.

A "burning glass," Fig. 6, also depends for its efficacy upon the fact that light travels with more difficulty through air than through glass. Figures 7 and 8 show how a triangular bit of glass known as a prism will impede the waves of radiant energy which fall upon it, and while these waves succeed in passing the barrier, their direction is turned. Figure 9 shows two of these prisms placed base to base, and their united action in bringing rays to a focus. A double convex lens is simply two prisms placed base to base. Burning glasses of great magnitude have been made. One made by Bernieres and Trudaine about a century ago was 4 ft. in diameter, and was hollow. When filled with water or other liquid through which radiant heat can pass, it produces heating effects sufficient to melt metals whose fusion point is very high. It is interesting to note in this connection that lenses have been made of ice, and by their use fire was readily produced. Gunpowder and paper were easily ignited by this queer kind of burning glass. Ice is certainly a strange agency through which fire may be brought into being.

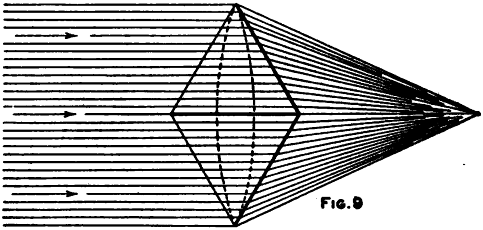


FIG. 9

Two prisms placed base to base. Dotted lines show ordinary double convex lens

Radiant heat is readily reflected. When mirrors are made with the special curvature known as parabolic, their power is almost unlimited as a means of heat concentration. A parabola is the same curve as is traversed by a stone which is thrown slantingly into the air, and returns to the ground. All rays of energy passing into a mirror shaped like this peculiar curve are reflected to one point called the focus, providing the rays enter the mirror parallel to a line at right angles to the exact center of the mirror. Conversely, rays of light, or heat, or sound, emanating from such a focus, are made parallel after reflection against the sides of the parabola. By combining two such mirrors, so that their axes exactly coincide, as shown in Fig. 10, it is possible to transmit heat quite a distance, and reconcentrate it upon some object. If a lump of ice be placed where the red hot coal is shown in Fig. 10 and a thermometer be substituted for the match, the thermometer will at once show a decided fall in temperature. At first thought, it might appear as though "cold" can be radiated as well as heat. This, however, is not so. "Cold" is simply the absence of heat. All bodies, as has been stated before, tend to equalize as regards temperature. The burning coal gives off heat, so does the match. The coal gives off more than it receives, while the match receives much more than it gives off. Hence the match ignites. When the ice is substituted for the coal, and the thermometer for the match, the mercury gives off more heat than it receives, and hence is reduced in temperature, and therefore contracts.

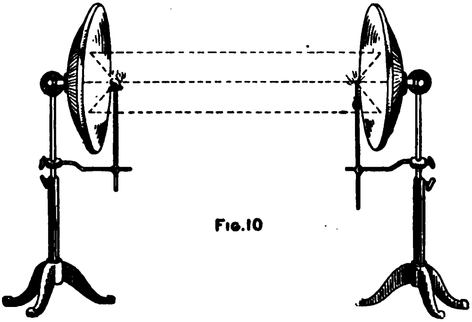


FIG. 10

Reflection of heat. Parabolic conjugate mirrors. Match ignites at a distance of 10 ft. from red hot coal

All bodies, it matters not what their composition is, radiate heat, or else absorb the same kind of rays which they give out when hot. A polished surface reflects but does not radiate. A dull surface, like lampblack, is a good radiator. A burnished coffee pot will retain its heat much longer than one that is tarnished. In other words, a good absorber is a good radiator, while a good reflector is a poor absorber and a poor radiator. As with light, radiant heat varies inversely as the square of the distance. In other words, a body placed at twice its former distance from a radiator will receive one-fourth the heat; at three times, one-ninth, etc.

Convection, the third method by which heat travels, is practically a form of conduction. Heated masses of air or water expand through the molecular action of the heat. They are therefore less dense than before, and are consequently pushed up by the descent of the colder and heavier masses. The moving particles give up their heat when brought into touch with colder bodies, and hence the statement that convection is practically the same as conduction. Heat transference in fluids is mainly by convection currents, and the circulation thus brought about produces the trade winds and ocean currents. In our homes, convection plays an important part, as it is by means of this principle that ventilation and systematic heating are secured.

CHAPTER VII

HOW HEAT IS MEASURED

A THERMOMETER tells us the degree of temperature, but it does not tell us anything concerning the quantity of heat that may be in a body. A pint of water at 10° C. is much cooler than an ounce of water at 80° C. but the pint contains more heat than the ounce. To attempt to estimate the heat of a body by its temperature would be just as absurd as to estimate the size of a river by its velocity without considering its volume. In that case, a mountain brooklet would be larger than the Amazon, and a fast running creek would be greater than the Mississippi.

Heat is measured by reference to some standard unit just as silk is measured by the yard, butter by the pound, or milk by the quart. Many different kinds of heat units have been suggested, but the most common, and the one most easily understood and most generally used in engineering practice is known as the British thermal unit, abbreviated as B. t. u. A British thermal unit is the amount of heat required to raise one pound of water one degree Fahrenheit. This is the yardstick of heat, and by its use we are able to estimate the quantity of heat in a pound of fuel, or to determine the ratio between the heat values of different substances just as easily as the grocer weighs out his sugar, or the draper measures off a definite length of calico.

As has been indicated, water is taken as the standard for the measurement of heat, just as it is taken as the standard of specific density. A cubic inch of gold weighs 19.6 times as much as a cubic inch of water. We therefore say that the specific density of gold is 19.6. Even as we find that the different substances such as gold, silver, copper, zinc, tin, and so forth, have different densities as compared with water, so we find that all substances have peculiar and distinct capacities for taking up this curious motion known as heat. A pound of iron, for example, at a temperature of 100° F. contains more than three times as much heat as a pound of gold at 100° F. and only one-ninth as much heat as a pound of water at the same temperature. Why is this? Again we are compelled to admit that we do not know. Even as some bodies are much better conductors of heat than others, so some bodies have a greater or lesser capacity for absorbing the vibrations which constitute heat. In Fig. 1 is shown a number of substances on a hot plate, all weighing the same amount and receiving the same quantity of heat. The cubes of course would not all be the same size, but are made so for convenience. The number placed on each cube indicates the degree of temperature to which it would rise while water rises one degree. The ratio between the amount of heat required to raise the temperature of a body one degree, and the same weight of water one degree is known as specific heat, and it is useful sometimes to know how to make this calculation. The operation is exceedingly simple, and depends upon the fact that when two bodies of different temperatures are placed in thermal contact, there will be a heat exchange exclusively between the two bodies, and one will lose what the other gains. For example, suppose we wish to

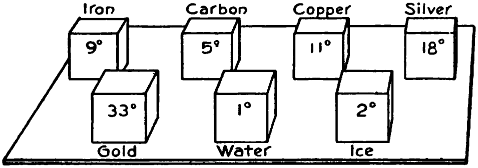


FIG. I

Equal Weights of Different Substances Showing Degrees of Temperature Each Would Rise While Water Rises One Degree.

determine the specific heat of some new alloy. First determine its weight and temperature; then place it in water of known weight and temperature. In a short time the alloy and the water will have the same temperature. If the alloy was colder than the water, its temperature would rise, and the temperature of the water would fall, and vice versa. The quantity of heat remains the same after the mixture as before. It is the relative amount that each substance rises or falls in temperature that tells the tale. If the alloy weighs one pound and the water the same, and the temperature of the alloy falls one hundred degrees, while that of the water rises five degrees, then 100 degrees of the alloy equals five degrees of the water, and we know the specific heat of the alloy is just one-twentieth of that of the water. The outline given below is a convenient form in which to express the facts stated above.

WATER	ALLOY
Amount taken…… ..1 lb.	**Amount taken……… 1 lb.**
Degrees of change.. .5	**Degrees of change ...5**
Specific heat ………1	**Specific heat………X**

$$5 = 100\ X$$
$$.05 = X = \text{Specific Heat of Alloy.}$$

In a former chapter mention was made of "latent" heat as it was termed by the early philosophers. Let us review our knowledge of it. Latent heat is a form of energy, locked up as it were within certain bodies, such as water and steam. If ice be placed in a pan of water, the thermometer will show a temperature of 32° F. Put the pan on the fire, the temperature of the water and ice will not rise but will remain at the freezing point until all the ice is melted. Let the water remain on the fire. Steadily the temperature will rise until the boiling point is reached, and there it will remain until the water is all evaporated. The heat given to the mixture of water and ice without changing the temperature was utilized by the ice in its transformation into water. Ice at the melting point, plus sufficient latent heat, equals water at the freezing point. Likewise the heat given to the water at its boiling point was utilized in the actual work done in changing water into steam. Water at the boiling point, plus enough latent heat, makes steam. Conversely, when water freezes or steam condenses, this energy, which has been locked up, reappears as "sensible" heat. Latent heat is most conveniently measured by the "mixture" method. For example, suppose it is required to determine the latent heat of water. This is done by adding water of known weight and temperature, to ice of known weight and temperature. Water at 32° F. added to ice at the same temperature will have no effect upon the ice. If the water be warmer, some or all of the ice will melt. Add, say, a pound of water, at 176° F. to a pound of ice at 32° F. The ice will melt, and the temperature of the mixture will be 32° F. In other words, the 144 degrees lost by the water is the price paid to the ice to become water. The latent heat of water is therefore 144 thermal units, since, as before stated, a British thermal unit is the amount of heat required to raise one pound of water one degree Fahrenheit, and the pound of water fell 144 degrees or, in other words, gave up 144 thermal units in converting the ice into water. The latent heat of steam is also easily determined. Water is boiled in a suitable vessel and the resulting steam passed into cold water whose temperature and weight are known. The steam will be condensed by the cold water, whose weight and temperature will thereby be increased. The added weight represents the amount of steam condensed. The rise in temperature represents the heat set free by the change from steam to water. Suppose the initial weight of the cold water was one pound. Its added weight is one ounce; its increase in temperature is about 60.5°. If an ounce of steam will heat a pound of water 60.5°, equivalent to 60.5

heat units, a pound of steam would set free 16 times that amount, or 968.4 B. t. heat units, the latent heat of steam, Of course this is only a rough calculation, as several minor factors must be taken into consideration in a calculation of this nature, but the method outlined will serve to give a general idea of how steam is compelled to tell us some of its secrets.

As a general thing heat causes bodies to expand. And now comes a curious fact, the reason for which we do not know. No two bodies have precisely the same rate of expansion, iron has one rate, gold another, aluminum another, and so on down through the list. Figure 2 represents the action of heat upon two equal strips of iron and brass riveted tightly together. The Bunsen flame will soon cause the compound rod to bow, the brass side being convex, as brass expands more than iron. Advantage is taken of the unequal expansion of different substances in the construction of the gridiron pendulum, in thermometers, thermostats, and the balance wheel of a watch, the consideration of which will be deferred to a later chapter. The same

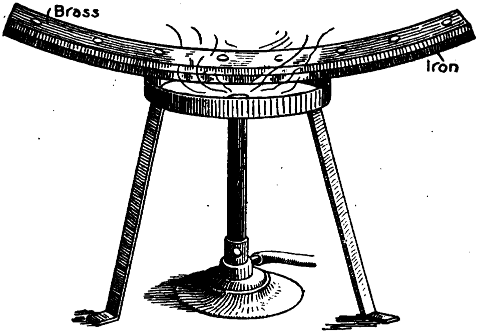


FIG. 2

Experiment Showing the Unequal Expansion of Iron and Brass

substance, however, always expands at the same rate, and it is sometimes of great importance to know precisely the amount of expansion of a given metal at a given temperature. The method of determination is easily understood. A rod of iron, say, is carefully measured, its length being determined to the thousandth of an inch, and its exact temperature noted. The rod is placed in a jacket around which steam at 212° F. is caused to pass. Suppose the rod is 3 ft. in length, and its temperature 62° F. When placed in the steam, it will of course become 212° F., a rise of 150 degrees. The rod is again carefully measured. The increase in length is due to the 150 degrees. Divide the increase by 150, and the amount of expansion caused by one degree will be known. Divide this answer by 3 (the length of the rod being 3 ft.) and the amount of expansion of one foot of iron for one degree of temperature, will be known. The number, which in the case of iron is .000012 inch, is known as the coefficient of linear expansion. In laying the rails of a railroad, the expansion of iron in summer and its contraction in winter must be taken into account. A blacksmith slips a red-hot tire over a wheel, and the tire is on to stay, as the subsequent shrinking makes a perfectly tight fit. A machinist shrinks a metal collar on a frame in the same manner, the pressure due to contraction being enormous.

And now we come to the consideration of the relation between heat and work. Everyone knows that hammering a nail will make it hot, but few people know that there is a direct numerical relationship existing between the amount of work done and the quantity of heat produced. Until the close of the eighteenth century heat was believed to be a fluid. Practically every scientist of note up to that time, with the exception of a few men such as Bacon, Locke and LaPlace, thought that the reason mercury occupied more bulk when heated was on account of an invisible fluid which permeated the mercury and caused it to expand. In 1798, Count Rumford noticed that the chips of steel resulting from the boring of a cannon in the military workshop of Munich, were so hot that he could not hold them in his hands. This puzzled Rumford, as he could not reconcile the theory that heat was a fluid with the fact that both the cannon and the chips were extremely hot, and that the heat had obviously arisen from the friction of metal upon metal and not from the advent of some unexplained fluid. While Rumford was trying to solve the puzzle, Davy, over in England, demonstrated that two pieces of ice rubbed together in a vacuum would produce heat enough to melt the ice. Obviously the heat could not have come from the ice, and it could not have come from the air, as that possible source had been eliminated. Whence, then, did it come? Rumford thought it was produced by friction, and in order to demonstrate the truth of his theory, secured a large piece of brass hollowed out at one end, and fitted into it a cylinder of steel weighing 5 tons. By an ingenious mechanical contrivance attached to the cylinder, the latter was made to revolve within the brass 32 times in a minute. Water was placed in a box around the brass, and at the end of two hours and a half the water actually began to boil. Work had been transformed into heat without the shadow of a doubt. This experiment of Rumford's was a death-blow to the theory that heat is a fluid, and was the foundation of the belief that heat is a form of motion. It was a good start on the road to the truth, but even Rumford and Davy did not suspect that there is an exact relationship existing between the heat evolved from friction and the amount of work done. Almost 50 years elapsed before this was determined. In 1843, Dr. Joule of Manchester, England, performed his classic experiment, which revealed to the world the mechanical equivalent of heat. Figure 3 is a diagrammatic representation of the simple apparatus used by Joule in his demonstration. A paddle was made to revolve with as little friction as possible in a vessel containing a pound of water whose temperature was known. The paddle was actuated by a known weight falling through a known distance. A pound falling through a distance of one foot gives a foot pound of energy. At the beginning of the experiment, a thermometer was placed in the water, and the temperature noted. The paddle was made to revolve by the falling weight. When 772 foot pounds of energy had been expended on the pound of water, the temperature of the latter had risen one degree, and the relationship between heat and mechanical work was found. Joule tried the same experiment again, using mercury instead of water, and verified his original discovery again and again. And what in plain language does this discovery mean? Simply this: the amount of energy required to raise a pound of water one degree Fahrenheit is suffi-

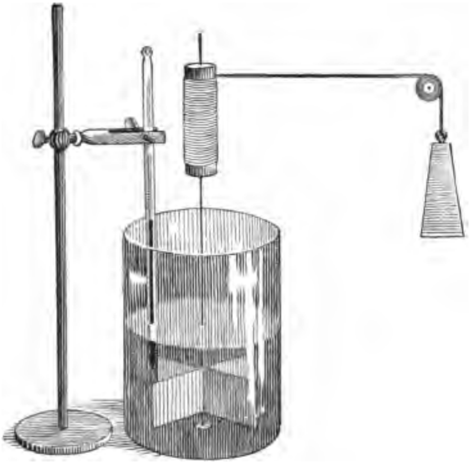


FIG. 3

Apparatus with Wnich Dr. Joule Found Mechanical Equivalent of Heat

cient to raise it 772 ft. against the force of gravity. Later determinations have shown that the correct figure is 778. One British thermal unit equals 778 foot pounds. The importance of this discovery cannot be overestimated, as it is the basis of practically all the calculations so essential in engineering practice relative to the construction of engines and the determination of their capacities as regards the work to be done.

* * *

CHAPTER VIII

EXPANSION AND CONTRACTION

EXPANSION is one of the most remarkable of the phenomena to be reckoned with in the natural world. Practically every bit of matter, from the great Brooklyn bridge to the tiny hairspring in one's watch, is under its imperial domination. It is a tremendous force, and the world of mechanics has to treat it with the deference and respect due to its gigantic power. Unlike gravity and other forces of nature, it is whimsical, and takes sudden fits and starts, now acting one way, now another. It affects different bodies in different ways, and seems to be at variance with the time-honored forces whose action can be predicted under all circumstances. At least that is what it apparently does. In our meager knowledge of the great underlying laws that control the universe, it is possibly unwise to speak so unkindly of expansion, as though it were a spoiled child in need of correction; its behavior, however, is so contrary to what one might expect, that one is at a loss to say anything else.

Take for example the peculiar action of heat upon water. A pint of water at, say, the boiling point, 212° F., occupies a certain definite volume. Allow it to cool, and the volume steadily shrinks until it reaches the temperature of 39° F. If the temperature of the water be lowered below that point, contrary to all expectation and understanding, the water begins to expand and will continue to do so until it reaches the freezing point. In other words, a pint of water at 39° F. is heavier than a pint of water at any other temperature. Why? We do not know. It is one of the peculiarities before referred to.

Of course, it is a good thing for us that water does not freeze at its point of greatest density. If that were so, ice would form at the bottom instead of the surface of a pond, and the rivers in the temperate zones would become literally solid masses of ice which the summer's heat could not melt, being protected by the non-conducting water above. This would go on, year after year, until practically the whole continent would become a mass of ice. It might appear at first thought that nature had designed this phenomenon with reference to man's convenience and comfort, but, as Tyndall pointed out years ago, the same peculiarity is true of other substances besides water, as iron and bismuth both expand upon freezing, and solid iron will float in liquid iron, even as ice will float in water.

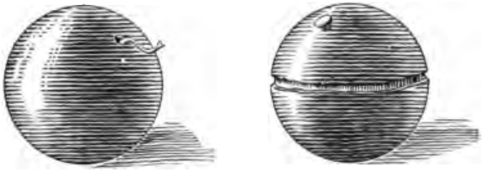


FIG. 1

Bombs Burst by the Expansion of Freezing Water

The force exerted by water in crystallization is enormous. As shown in Fig. 1, thick shells of iron filled with water will break like piecrust when the confined water freezes. We are, unfortunately, on familiar terms with the plumber during the winter season on this account. Some years ago, an ingenious device was patented by an English surgeon to obviate the usual results of the freezing of water in exposed pipes. A rubber tube is placed within a water pipe and of such diameter that the space inside the tube is a little more than equal to the increase in volume of the water by freezing. The rubber tube is filled with air, and when freezing takes place with consequent expansion, the air will be compressed instead of the pipe being split asunder. Another wrinkle, just as simple, consists in pounding or compressing exposed lead pipes until they assume an elliptical shape. The expansion due to the freezing of the water will cause the pipe to reassume the circular form, and thus allow for the increased volume required by the ice.

About the only reasonable hypothesis which will explain the changes in volume caused by freezing and melting, is that of Tyndall, who assumed that the molecules of a body are really little magnets, and that the attraction and repulsion of these magnets cause them to form combinations that occupy more or less space, even as a thousand bricks could be arranged in a multiplicity of ways. This theory also explains, to a degree at least, the fact that wrought iron, iron wire and cast iron have different rates of expansion.

Certain crystals, such as the emerald and Iceland spar, when they increase in length in one direction, contract in another. Rubber and iodide of silver are also exceptions to the general law that heat causes expansion, while the absence of heat causes contraction. Dried wood has not the same expansion rate in the direction of the fibers, and perpendicular to their direction Clay, even when completely dried, will contract when it is submitted to an increasing temperature, and advantage is taken of this peculiar fact in the construction of clay pyrometers for the determination of the temperature of large kilns.

The expansion rates of platinum and glass are practically the same. Upon this fact depends one of the world's great industries, the manufacture of incandescent electric-light bulbs. The current passes the glass walls of the bulb by means of tiny platinum wires, and these wires contract and expand at almost exactly the same rate as the enveloping glass. If this were not so, a vacuum could not be preserved in the bulb, and the delicate filament would be oxidized almost as soon as the bulb warmed up. A fortune beyond all comparison, lies within the grasp of the lucky individual who will provide a substitute for the platinum, as platinum is quite rare and expensive, and something must be done soon, owing to the limited supply of this metal in sight.

The walls of a building are sometimes rectified by the enormous force exerted by the contraction of iron rods. Bars of iron are placed so as to join the two walls where the bulging is most pronounced. These bars terminate in screws furnished with nuts. The whole of their length is heated and the nuts tightened. On cooling, the bars will contract with practically irresistible force, causing the walls to straighten up. This operation is repeated until the rectification is complete. Boiler plates are fastened with red-hot rivets. The contraction of the rivets incident upon their cooling draws the plates tightly together, forming a steam-proof joint.

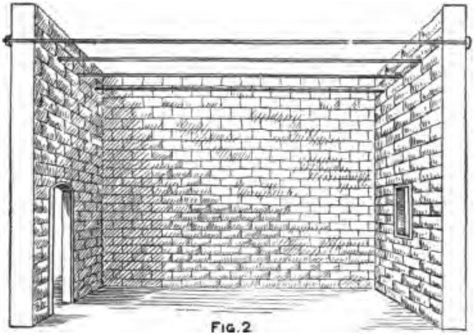


FIG. 2

Rectification of Walls by the Contraction of Iron Rods

Tyndall, in his work on heat, gives an excellent illustration of the force of expansion and contraction. "The choir of Bristol cathedral was covered with sheet lead, the length of the covering being 60 ft., and its depth, 19 ft. 4 in. It had been laid in the year 1851, and two years afterwards it had moved bodily down for a distance of 18 in. The descent had been continually going on from the time the lead had been laid down, and an attempt to stop it by driving nails into the rafters had failed; for the force with which the lead had descended was sufficient to draw out the nails. The roof was not a steep one, and the lead would have rested on it forever, without sliding down by gravity. What, then, was the cause of the descent? The lead was exposed to the varying temperatures of day and night. During the day, the heat imparted to it caused it to expand. Had it lain upon a horizontal surface, it would have expanded all around; but as it lay upon an inclined surface, it expanded more freely downward than upward. When, on the contrary, the lead contracted at night, its upper edge was drawn more easily downward than its lower edge upward. Its motion was, therefore, exactly like that of a common earthworm; it pushed its lower edge forward during the day, and drew its upper edge after it during the night, and thus by degrees it crawled through a space of 18 in. in two years."

A Prince Rupert drop, or Dutch tear, is a curious and familiar example of the effect of contraction and expansion. Melted glass is dropped into ice-cold water and a small, pear-shaped mass of glass, shown in Fig. 3, is formed. The rounded end is hard and tough and will resist considerable pressure. If the filament end, however, is broken, the whole mass will immediately disintegrate into a fine powder with explosive violence. If the operation be performed in a flask filled with water, the shock will be sufficient to break the flask. The explanation is simple. The drop of hot glass is suddenly cooled, and a thin skin of cooled glass is stretched tightly over the body of the drop, inclosing the interior mass which has not had time to solidify. When this interior mass does cool, it produces a state of intense strain. The effect of the contraction is exercised equally on the whole mass, and, notwithstanding the strain, the drop remains in equilibrium.

This equilibrium, however, is instantly destroyed when any part of the drop is fractured, and the unbalanced strain causes the drop to fly to pieces.

Mention has been made in a preceding chapter of the effect of unequal expansion upon two different metals that have been bolted together. It is upon this principle that the action of the ordinary thermostat, so familiar now as a controller and regulator of the temperature of large buildings, is explained. This device is shown in Fig. 4. R is a rod made up of two different metals whose rates of expansion are different. When the temperature of the room in which the thermostat is placed becomes too high, the rod curls toward the metal point S and touches it, completing an electrical contact, which causes a motor to shut off the draft. When the temperature of the room falls below a certain point, the rod curls in the opposite direction toward the metal point T. This causes

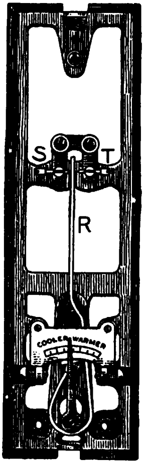


FIG.4

Ordinary Thermostat

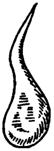


FIG.3

Dutch Tear

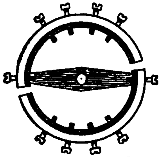


FIG.5

Balance Wheel

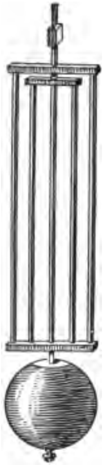


FIG.6

Gridiron Pendulum

a motor to open the draft and thus furnish a more abundant supply of hot air.

Everybody, in these days of cheap and reliable timepieces, carries a watch. And yet there are very few who appreciate the methods and devices by means of which the troublesome expansion and contraction of metals are corrected, in order that a watch may keep correct time. The balance wheel of a watch corresponds to the pendulum of a clock, and any variation in its dimensions will cause it to move faster or slower, as the case may be. The hair-spring is really a long strip of metal which becomes weakened in its effect when expanded by an increase in temperature, and has its power augmented when contraction takes place.

To correct both of these conditions, the rim of the balance wheel is made up of two different metals, the outer part brass, the inner part iron (see Fig. 5). When the hair-spring becomes weaker by expansion, the brass of the balance wheel also expands; but as it expands more than the iron to which it is bonded, it curls in toward the center of the wheel, making practically a wheel of smaller diameter, and causing the same effect as is produced when a clock pendulum is shortened. Exactly the opposite conditions obtain when the timepiece is exposed to extreme cold, and the balance wheel has its diameter increased, thus causing a slowing up to counteract the increased strain produced by the contraction of the hair-spring. The same principle is applied in the construction of first-class clocks. Any uncorrected variation in the length of a pendulum is fatal to the timekeeping quality of a clock. A gridiron pendulum (Fig. 6), made up of alternate rods of steel and brass, serves to correct the result of the expansive force. The central steel rod passes through holes in the lower horizontal framework, and supports the bob at the lower end. The steel rods are so arranged that they will expand downward, while the brass rods expand upward, and the total length of each metal used is exactly sufficient to counteract the other's expansion, and the center of the bob will remain at a constant distance from the point of suspension.

Figure 7 is a representation of the mercury type of pendulum. The rod to which the bob is attached expands downward while the mercury in the two compartments expands upward. By careful experimentation, the exact quantity of mercury necessary to preserve an even balance may be determined. Of course, the gross length of the pendulum varies, but as the real length of a pendulum is the distance from its point of suspension to its center of gravity, in the mercury type of pendulum, the center of gravity remains constant.

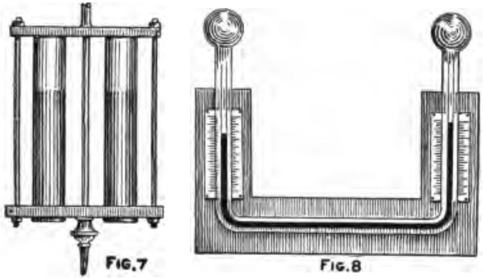


FIG. 7 FIG. 8

Mercury Type of Pendulum and Leslie's Differential Thermoscope

The metallic thermometer already referred to in a former chapter is an ingenious device whose action depends upon the principle that different metals have different rates of expansion. As this thermometer was fully described, its explanation will be omitted here. Leslie's differential thermoscope (Fig. 8) consists of two bulbs connected by a tube containing colored sulphuric acid. If one of the bulbs be warmer than the other, the acid will move toward the cooler bulb, due to the expansion of the air in the warmer bulb. This thermoscope is extremely sensitive to temperature differences. Rumford's thermo-

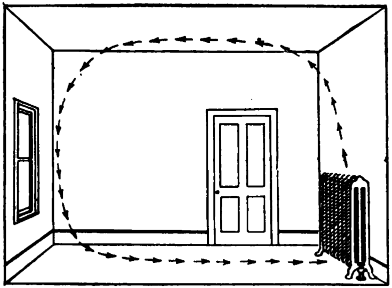


Fig. 9

The Circulation of Air in a Room Heated by a Radiator

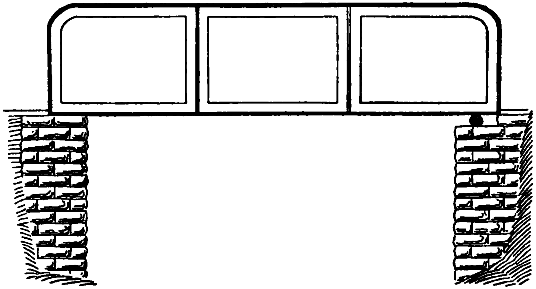


Fig. 10

Roller (on right) Providing for Expansion of Iron Bridge scope acts upon the same principle as Leslie's, but has a longer horizontal arm, and contains alcohol instead of sulphuric acid.

Owing to the fact that gases expand much more than solids or liquids, the balloonist who seeks the higher altitudes is in considerable danger. The hydrogen gas or coal gas with which his balloon is filled, expands under the influence of the unobstructed rays from the sun, and also on account of the lessened atmospheric pressure. Instances are on record showing that balloons have burst from these causes. The United States Weather Bureau sends up into the higher reaches of the atmosphere large numbers of what are termed "sounding balloons." These balloons carry automatic registering apparatus for recording important data of the aerial ocean. At a certain altitude the rubber bag containing hydrogen bursts, due to the expansion of the gas, and the instruments descend by means of a parachute to the ground.

The contraction of a gas by cooling causes a balloon to become flabby and unwieldy. This is corrected by means of a second bag, called a "ballonet," which is placed within the main balloon, and may be inflated with air by means of a motor, thus maintaining the shape of the balloon. When the hydrogen expands to the danger point, the volume of the balloon may be regulated by letting the air in the ballonet escape through easily controlled valves.

The most important industrial application of the fact that gaseous bodies will readily expand and contract is in the matter of ventilation. Hot air rises. Cold air falls. By taking advantage of these facts, the problem of proper ventilation is easily solved and a steady circulation of air insured, as shown in Fig. 9.

CHAPTER IX

ENERGY AND FUELS

THE fairy tale of yesterday is the science of today. In our wide-eyed childhood days we pored eagerly over the wonder stories of the Brothers Grimm, or listened with awed attention to the prodigies and marvelous deeds of Baron Munchausen and Sindbad the Sailor. Well do we remember the man by the wayside who refused to doff his hat, as by doing so a killing frost would blight everything in his vicinity; likewise do we call to mind that other happy individual, the fortunate owner of the famous seven-league boots, who was able to walk comfortably around the earth in a single day.

All these wonderful tales sink into insignificance beside the simple facts of modern science. A few turns of wire whirling in front of a magnet, and lo! we have a light that rivals the sun in its intensity, or a silent power that turns all the wheels in our factories. A whisper in New York may be heard in Chicago. The President of the United States touches a button in Washington and ponderous machinery is energized in the far-off Philippines.

A steamship far out at sea flashes "C Q D" into the murky fog of the night; instantly sister ships, scores of miles across the horizon, respond and turn their prows in her direction. A few buckets of water confined within an iron box will carry a heavy locomotive and its train of Pullmans 60 miles an hour. A few pounds of piano wire and a dozen yards of muslin enable us to go sight seeing into the very air itself, outwinging the birds in swiftness of flight. A few tiny bits of curved glass tell us the exact composition of suns and stars billions of miles away in the vast expanse of the heavens.

Whether it be electricity, magnetism, steam, wood, coal, oil or gas that is the direct agent in the production of power, it is the sun, after all, that is the source of all the energy in the world. For ages and ages the sun has been bathing the earth with her radiant energy, and storing up for us in mighty caverns enormous supplies of energy in the form of coal, oil and gas. To look at a bit of coal, grimy and stony in appearance, one would hardly suspect that it is practically preserved sunlight and heat. Let us look a little into this matter of coal, and attempt to account for its wonderful properties, and learn just how it received its fuel power.

First of all we must bear in mind that even as matter is indestructible, so is that strange and mysterious something known as energy. Even as there is just as much matter in the universe today as there was in the beginning, there is just as much energy. No energy is ever lost except in a practical sense. The stones that were carried to the very pinnacle of the Great Pyramid, retain to this day the energy of position given to them ages ago by workmen who have long since turned to the dust whence they sprang. The Washington monument is not only a memorial to America's greatest citizen, but it is also a storehouse of work done by others of its citizens.

Coal was formed from plants that flourished millions of years ago and which were prevented from oxidation by the fact that they fell into swamps and morasses and were covered with a protective layer of water. Afterwards they were entombed under billions of tons of sandstone, limestone and clay. The resulting pressure and heat caused the vegetable matter to assume the form of coal in which state it is familiar to us. Clearly it was not the water, nor the pressure that gave the coal its store of energy. It must have received it while it was still a member of the plant world. Wood will burn. Grass will burn. Corn will burn. All plants will burn. Coal was formed from plants.

Evidently plants are the storehouses of energy. How do they get it? In this way: A plant cell is a chemical laboratory whose secrets have been, and still are, the envy of every chemist. When the sunlight aids it, a plant has the power of chemically combining water with a gas known as carbonic oxide, the same gas that is given off by animals in breathing. The product of this composition is known as starch, cellulose or woody tissue. While the plant is able to form the actual combination of gas and water, it is the sun's energy, after all, that gives it the

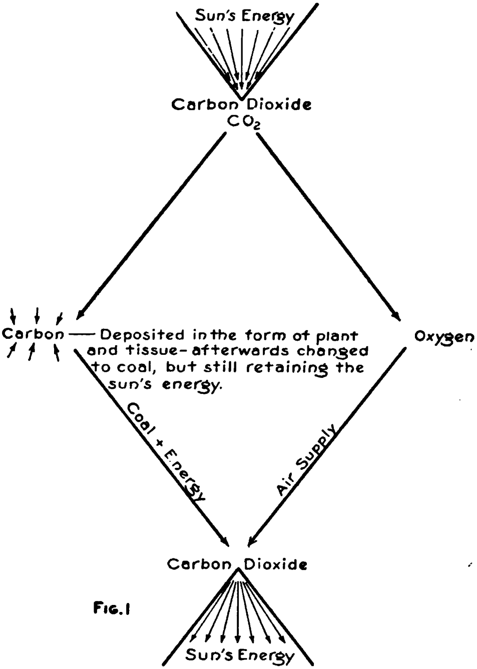

Sun's Energy
Carbon Dioxide
CO_2
Carbon — Deposited in the form of plant and tissue - afterwards changed to coal, but still retaining the sun's energy.
Oxygen
Coal + Energy
Air Supply
Carbon Dioxide
Sun's Energy

FIG. 1

Diagram Showing the Storing of Energy in Coal, and its Release in After Ages by the Addition of Oxygen

power to do so. The sun does the actual work, using some of its own energy in the operation. To raise a pound one foot, requires one foot-pound of energy. To do any kind of work, physical or chemical, requires energy which may be stated in terms of foot-pounds.

The energy of the sun in helping the plant in its work of chemical combination, is just as much work and of practically the same kind as that put forth by a laborer in carrying a hod of bricks up a ladder. And even as the energy used by the laborer remains at the top of the ladder, so does the energy used by the sun remain within the wood built up by the plant and the sun. When the wood, or what is the same thing, the coal, is placed under proper conditions, namely, sufficient heat and abundance of air supply, the wood returns to its original components, water and carbonic oxide gas, and the sun's energy that has been imprisoned within the wood or coal is set free in the form of heat, the lowest form of energy. Look at the diagram shown in Fig. 1, and the simple changes and transformations will be readily understood.

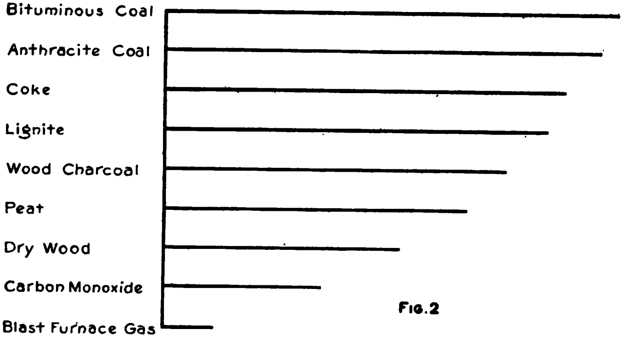


FIG. 2

Relative Values of Various Fuels

As is the story of wood and its wonderful power of locking up energy, so is the story of oil, of natural gas, of producer gas, of illuminating gas and of every other fuel known to man. Directly or indirectly they are children of the sun, and it is the sun's energy that is given back by them to man. There are many different kinds of coal varying from peat which is the first station on the way to the kingdom of coal, up to anthracite, which is almost pure carbon, having lost almost every other constituent. The value of coal is estimated principally by the number of heat units it can give off. Let us recall just what a heat unit is. A British thermal unit, abbreviated B. t. u., is the amount of heat required to raise a pound of water through one Fahrenheit degree. The table given herewith, compiled from the Practical Engineer, shows the relative heating values of the different coal fuels.

HEAT VALUE OF VARIOUS FUELS AND COMPOSITION

Name of Combustible	Composition C	H	Volatile Matter	Ash	Caloric Power B.t.u.
Carbon	1.00	....	....	....	.....
Anthracite Coal	0.90	0.03	0.03	0.01	13500
Bituminous Coal	0.85	0.05	0.06	0.06	14400
Lignite	0.70	0.05	0.20	0.05	11700
Peat	0.55	0.05	0.30	0.10	9000
Peat 0.20 water	0.39	0.04	0.50	0.07	7200
Coke	0.85	0.05	....	0.10	12600
Peat-charcoal	0.82	....	....	0.18	9000
Dry wood	0.48	0.06	0.05	0.01	7200
Wood 0.20 water	0.40	0.05	0.25	0.01	5400
Wood-charcoal	0.80	....	0.04	0.07	10800
Hydrogen	..	1.00	....	....	62000
Carbonic oxide	0.43	....	0.57	....	4320
Illuminating gas	0.62	0.21	0.17	....	18000
Blast-furnace gas	0.06	0.02	0.92	....	1620

It will be observed from this table that the value in heat units of coal or other fuel depends practically upon its percentage of carbon. Anthracite has the largest percentage of carbon, but does not give off the greatest number of heat units, being a little behind bituminous coal in that respect; the gas from a blast furnace has the lowest quantity of carbon and gives the least number of heat units.

The size of coal used in a furnace has a great deal to do with its efficiency as a heat producer, and manufacturers are giving this matter careful consideration. Coal known as "run of mine" varies from huge lumps down to slack and dust, commercially known as "culm." Lump coal averages 5 in. in diameter, and the other varieties known as "egg," "chestnut," "buckwheat," "barley," etc. indicate by their names their relative sizes. It has been learned by practical experimentation that with a chain grate stoker the work done by the coal increases with the size of coal up to a diameter of about ¼ in. and then decreases until the diameter is about 0.45 in., and then again increases. In fine coals there is a tendency to close up the draft holes, and thus perfect combustion is prevented and a large percentage of ash formed. The enormous quantity of fine dust necessarily produced in the mining of coal is sometimes made use of in the form of "briquettes." A suitable binding material, such as flour or pitch, is used to give coherence to the coal dust when compressed into bricks.

Pure hydrogen, of course, is not a carbon fuel, and the energy set free by the combination of this gas with oxygen, is similar to that obtained by the use of Thermit, or in connection with the frightful heat of the electric furnace. Peat, as has been said, is half formed coal, and cannot rival coal as a fuel where coal may be readily obtained. In localities where peat is abundant, and coal is unavailable on account of the expense of transportation, peat is used with success as a fuel. It burns with a bluish flame when first ignited, and continues to do so until the grate bars and spaces are covered with glowing embers. The flame then changes to an intense yellow, and at this stage it sets free its greatest heat. Peat is an excellent producer of gas, and it is used widely for illuminating, heating and furnace purposes. In Sweden it is used in the production of the famous Siemens-Martin steel, and also as the motive power in the operation of gas engines.

Wood, as a fuel, has about one-half the value of soft coal. A pound of coal is taken as the equivalent of 2.5 lb. of dry wood. A ton of bituminous coal equals about 2.12 cords of wood.

In the Southland, in the midst of the sugar industry, the refuse left after the sugar is extracted from the cane, is used as a fuel and is known as bagasse. Each ton of crushed cane will yield the equivalent of 12 lb. of coal. Owing to its presence as a by-product, bagasse is a cheap fuel and is largely used in the refining of sugar.

In certain favored portions of the United States, natural gas is available as a fuel. This gas was formed in the earth as the result of the chemical decomposition of carbonaceous matter. Its composition is mainly marsh gas, a compound made up of four parts of carbon and one of hydrogen. Figure 3 shows the relative heating values of the various gases used as fuels. Water gas is produced by passing steam over red-hot coke or coal, and afterwards enriching it with benzine. Blast furnace gas is formed, as its name would indicate, from the chemical decomposition that takes place when pig iron is reduced from iron ore, and is used to a greater extent than formerly. It has high value as a fuel in connection with gas engines, when rid of the dust that is commonly associated with it. Oil gas is produced by the distillation of oil and other liquid hydrocarbons at a very high temperature.

Oil is an ideal fuel, as it has many advantages over all other forms. It has a high heat value and occupies a comparatively small bulk. It is easily stored and easily applied to the furnace. It is transported from well to distribution point by its own gravity. It gives a more equal distribution of heat in a furnace. It does not cake nor form clinkers and cinders. It is free from sulphur, thus adding to the life of boiler plates. It has greater steaming capacity than coal, and on the whole it is greatly to be preferred over all other forms of fuel. It is the crude petroleum that is used, just as it comes out of Mother Nature's laboratory, as the increase in cost of the refined product is greatly in excess of the increase in fuel value. It has been demonstrated that while a pound of anthracite coal will convert 9.7 lb. of water at the boiling point into steam, and a pound of bituminous coal will vaporize 10.14 lb. of water at the boiling point, a pound of fuel oil will transform 16.48 lb. of water at 212° F. into steam at the same temperature, thus illustrating in a practical way, the great fuel value of oil. It is quite probable that in the near future, oil will supplant coal on the larger, ocean-going steamships.

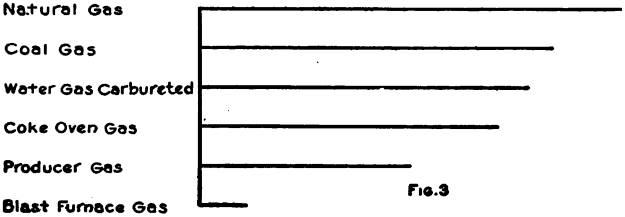


FIG. 3

Relative Fuel Values of Several Gases

CHAPTER X

THE MANUFACTURE OF ARTIFICIAL ICE

MAN has always been able to provide against the rigors of winter, and to protect himself from the inclemency of the weather when the sun has withdrawn its kindly influence. Whether it was the cave of our remote ancestors, or the steam-heated apartments of today; the skins of animals, or the finely woven cloth of modern times, man has always been able to fight his mortal enemy, cold. On the other hand, he has been practically at the mercy of the broiling sun during the summer season, for thousands of years. Occasionally he stored up some of winter's ice in caves or ice-houses, or else brought it at great expense or trouble from the glacier fields, if they chanced to be within a reasonable distance. The great mass of humanity, however, had to stand the baking and the sweltering, with as little perspiration and as much philosophy as possible, until the advent of artificial ice.

Today, every city, town or village has its up-to-date ice plant, and ice, within the past quarter of a century, has become a necessity instead of a luxury.

The principle involved in the manufacture of ice is exceedingly simple. Withdraw sufficient heat from water —the result is ice. The tiny little quiverings that constitute heat are the arbiters that determine whether a body shall be solid, liquid or gaseous. Man has known this for centuries, but it is only within comparatively recent years that he has made practical use of his knowledge.

Professors in hundreds of colleges and high schools, during the past century, have produced ice artificially before their classes, but the operation ended with the formation of a thin sliver of ice in the heated class room. The pupils were duly impressed, exclaimed: "Wonderful,"— and then passed on to the next experiment. No one bothered about the important principle that had just been demonstrated. No one thought of its meaning and its possibilities. No one saw in it the lessening of infant mortality, the husbanding of perishable products of farm and mill, and the possible addition to the sum total of the world's happiness and comfort.

Figure 1 is a representation of the simple apparatus by which ice in small quantities may be made experimentally. A thin watch crystal, covered with a film of water on its lower side, is placed on a block of moist wood. A little ether is poured into the glass, and a blast of air is directed against the ether. The ether rapidly evaporates owing to the relatively large volume of air that comes into contact with it. There is a price to be paid before a liquid can become a vapor or gas. This price is heat. We see this illustrated every day in the kitchen when the housewife boils water on the hot stove.

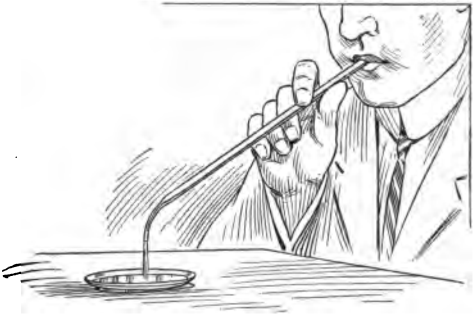


FIG. 1

The watch crystal contains ether. The rapid evaporation produced by blowing upon it causes a thin film of water between the watch crystal and block of damp wood to freeze.

The ether has to steal the heat necessary to enable it to soar into the kingdom of vapor, and it steals it from the nearest object, namely the watch glass. The watch glass, in turn, robs the thin film of water underneath of some of its heat, and as a result, since the water has lost the vibrations that enable it to exist as water, it is reduced to ice.

Figure 2 represents another experiment, full of significance, and performed millions of times in the last century. A glass of water is placed under the bell jar of an air pump, and beside it, a cup of sulphuric acid. When the air is withdrawn from the receiver, the lessened atmospheric pressure on the water stimulates evaporation. The water in the glass takes advantage of the excursion rates into the vapor state, borrows the price in heat units from the water remaining in the glass, and evaporates. The sulphuric acid promptly absorbs the venturesome vapor, leaving the air in the receiver as rarefied as before. More water evaporates, all at the expense of the water remaining in the glass. Finally enough heat units are taken from the water to lower its temperature to the freezing point. Further evaporation produces ice.

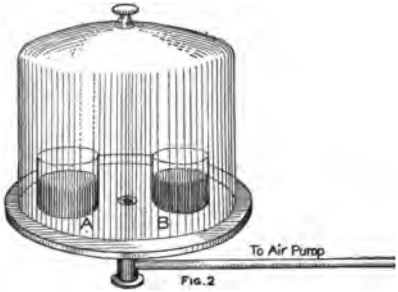


FIG. 2

A contains water; B, sulphuric acid. The lowering of air pressure and consequent evaporation of water, causes the remaining water to freeze. The acid absorbs the vaporized water.

About 40 years ago, Edmund Carre, a Frenchman, made use of the principle involved in the above experiment, in freezing water in decanters for use in the restaurants of Paris. The apparatus employed by Carre resembled a small steam boiler. This was partly filled with pure sulphuric acid and connected by pipes with an air pump and the flask containing the water to be frozen. The working of the pump caused the water to freeze by self-evaporation, the vapor being taken up by the concentrated acid. The acid was constantly agitated to prevent the formation of a layer of dilute acid on the surface. By this method ice was made at a cost not exceeding one-half a cent per pound, as the dilute acid produced in the operation could readily be sold for a variety of purposes, and was in no sense a waste product.

Another experiment that has delighted and bewildered the boys and girls of our higher schools for many decades is that of the cryophorus. With this bit of simple apparatus, ice has been made to appear in a hot classroom, right before the eyes of the interested students, even though the freezing mixture used was quite remote from where the ice finally appeared. It consists of a sealed tube with bulbs at either end. Only water and the vapor of water is contained in the apparatus. All the water is first shaken down into the lower bulb. Then the upper bulb is placed in a freezing mixture of ice and salt, as shown in Fig. 3.

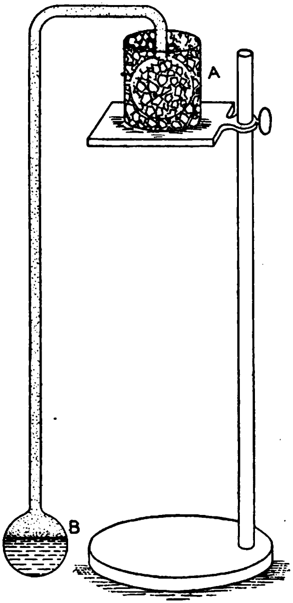


Fig. 3

A is empty, except for water vapor. It is surrounded by freezing mixture. Ice forms on surface of water in B.

In a few minutes, crystals of ice appear in the lower bulb, contrary to what the average person would expect, as the water thus frozen is as far as possible from the freezing mixture. This is the explanation. The freezing mixture around the upper bulb rapidly cools the invisible water vapor in the upper bulb, and causes it to condense. This lowers the vapor pressure on the water in the lower bulb, and renders its evaporation more easy. Evaporation rapidly follows as a consequence, and the vessel is soon filled again with water vapor. Evaporation requires heat. This heat is taken from its only possible source—the water remaining in the lower bulb—and as this process goes on continuously, the same water is robbed of its heat units sufficiently to cause it to go into bankruptcy, in other words, into ice, and the mystery is explained.

We are all quite familiar with the pulse glass shown in Fig. 4. This apparatus has something very important to tell us in our study of the manufacture of artificial ice. The liquid contained in the pulse glass is sulphuric ether which boils at the low temperature of 95° F., just about three degrees below the normal temperature of the human body. When the hand is placed around the bulb containing the ether, the ether rapidly moves over to the other bulb, where it soon begins to boil vigorously. At the instant the boiling begins, the hand on the empty bulb experiences the sensation of extreme cold.

As a matter of fact, the ether abstracts some of the heat from the hand in order that the boiling (evaporation) may go on, thus showing in an objective way, that heat is necessary to change a liquid into a vapor. Another fact of great importance that must not be lost sight of is that heat is required not only to change a solid into a liquid, or a liquid into a vapor, but also to permit a vapor or gas under great pressure to assume a condition of less pressure—in other words, to allow it to expand. Compressed air, for example, if released through a small orifice will expand, but the expansion is at the cost of sundry heat units that will be absorbed from any substance capable of parting with them in the vicinity of the expanding air. As a matter of fact, compressed air was one of the first gases used in the manufacture of artificial ice, but compressed air has given place to other gases that use the latent heat of gases rather than their sensible heat.

There are practically only three substances that are used today as ice-makers and of these three, the last is by far the favorite. These substances are: liquid carbon-dioxide gas (the gas that is dissolved in water to form "soda water"); liquid sulphur-dioxide gas (the gas that is formed when sulphur is burned in air); and liquid ammonia gas.

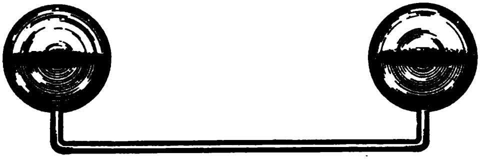


FIG. 4
Pulse Glass

Of course, ether is a first-class refrigerant, but the comparatively high cost of this substance, and the fact that it forms a highly explosive mixture with ordinary air, puts it out of the running with its rivals. The objection to carbon-dioxide is based on the fact that it can be worked only under very high pressures, varying from 900 lb. to 950 lb. per square inch, while sulphur-dioxide and ammonia work at very low pressures.

Ammonia is the gas most commonly used today as a refrigerating medium. It is cheap, easily compressed, and is easily deprived of any moisture, thus forming what is known as anhydrous ammonia. Ammonia is a gas made up of one atom of nitrogen and three atoms of hydrogen. It may be generated by heating animal products such as hair, horn, dung, hoofs, nails, etc. The common name for it, in fact, is "spirits of hartshorn," referring to the ancient mode of manufacture. Ammonia gas is a curious substance. Made up of two odorless gases, it nevertheless possesses one of the most powerful odors known to chemical science. The ammonia so commonly used in our households is simply an aqueous solution of the gas.

When the pure gas is compressed and cooled sufficiently, it becomes a liquid, and it is in this form that it is used as an ice-maker. When liquid ammonia is permitted to evaporate under ordinary atmospheric pressure, its temperature is 28.5 degrees below the Fahrenheit zero. If the pure, anhydrous, liquid ammonia is cooled to a temperature of —115° F., it becomes solid, and, curiously enough, it loses almost all of its characteristic odor —one of the marvels of low temperature. At a temperature of 900° F., ammonia gas breaks up into its constituents, nitrogen and hydrogen. The boiling point is about —28° F., its specific gravity is about 5/8 of that of distilled water, and a gallon of it weighs 5.3 lb. Its latent heat of evaporation is about 530 thermal units at a temperature of 32° F.

The ammonia used in ice-making is derived from ordinary soft coal. When soft coal is distilled, a very complex product is the result. Ammonia is one of the gases given off, and is taken up by water. The ammonia water thus formed is heated, and the gas driven off, rendered anhydrous, compressed into the form of a liquid, and is then driven into steel cylinders. These cylinders contain 100 lb. of pure anhydrous ammonia, and are never quite filled, in order that room may be allowed for the expansion of the liquid arising from variations in temperature.

The cylinders containing the ammonia are connected to long coils of iron pipe, and the gas allowed to escape into them through a valve. Immediately, like a school boy let out for a recess from a pent-up school room, the liquid ammonia scampers through the pipes, rejoicing in its newly found, but temporary, liberty. The liquid speedily changes to the gaseous form; but, as has been demonstrated in the experiments described in the beginning of this chapter, such change of state demands heat, and the heat is immediately taken from the iron coils. These expansion coils may be exposed to the open air, in what is known as the direct expansion system, circling a number of times about a room designed for cold storage purposes. If the object is the production of ice, the expansion coils are immersed in a heavy brine, into which are placed large oblong iron boxes, filled with water.

Steel Cylinders, Each Containing 100 Pounds of Pure Liquid Ammonia

The expanding gas robs the coils of some of their heat; the coils in turn take heat from the brine; the brine takes it from the iron boxes; the iron boxes in turn absorb it from the water, and the water freezes.

Figure 5 will give one an idea of the arrangement, diagrammatically, of the different elements entering into the process. An apparatus of this kind, as shown in the figure, would be expensive in operation, as it does not provide for the saving of the ammonia gas. This gas costs about $200 per ton of ice-making capacity. Accordingly, the ammonia, after it has done its work, and is quite hot, is not allowed to escape, but by means of con-

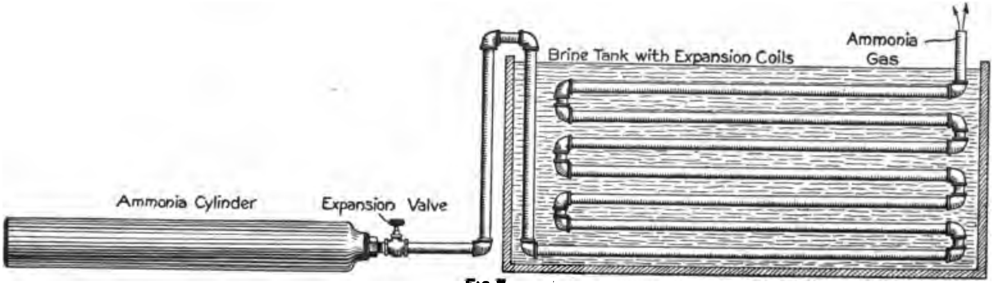
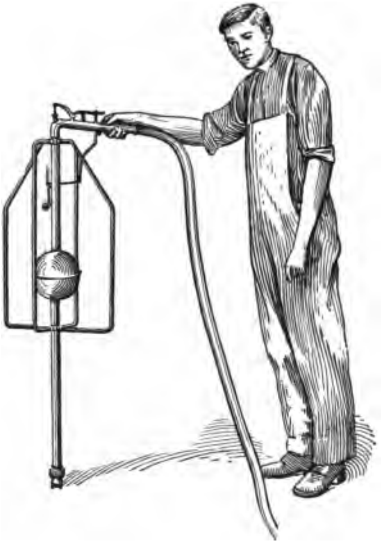


Fig. 5

Elemental Ice Apparatus

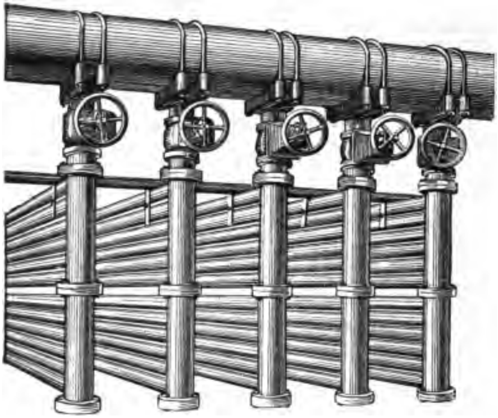
denser pipes, over which large quantities of cold water are constantly flowing, is cooled, and then by means of powerful compressor pumps, caused to reassume the liquid form, and may be used over and over again, little of it being lost in the process.

The floor of an ice plant looks like an enormous checkerboard. The squares are the wood covers of the iron tanks immersed in the brine. It takes about 48 hours to freeze the water thoroughly, and thus make a block of ice of the size and dimensions so familiar to the passer-by on the streets of our cities. The reason it takes such a long time to freeze is due to the fact that the ice forms first along the six sides of the container. This makes an insulating coat that hinders the absorption of the heat units from the interior of the ice box so formed.



Filling Device

A device, called a "filler," is used to place exactly the right amount of water in each tank. A float automatically shuts off the water supply by releasing a trigger when the tank has received its exact quota. The tanks are filled from the bottom upwards, an important matter, as it prevents the admission of air to the water. It is quite curious that air, although perfectly colorless itself, will make "milky" ice. The same phenomenon may be observed when the "white" of an egg is beaten briskly, or when the propeller of a steamship vigorously churns the water.



The Condenser Which Lowers the Temperature of the Compressed Gas, to Enable it to Return to Liquid Form

An ammonia compression plant consists of practically four parts: The expansion coils; the compressor into which the gas is drawn and compressed; the condenser, which lowers the temperature of the compressed gas sufficiently to enable it to return to the liquid form; and the receiver where the liquid ammonia is stored until it is needed for another ice-making tour.

It requires 45 cylinders of ammonia of 100 lb. each to make 100 tons of ice. In many ice factories, the water ordinarily is not pure enough, and a distilling plant is a necessary adjunct. As regards the quantity of pipe used in the best factories for condensation purposes, it requires about 320 ft. of 1½-in. pipe to the ton of the ice-making capacity. The brine is generally made from common salt, but calcium chloride forms a better brine that will not freeze, as occasionally happens in the case of salt brine.

The Finished Product

CHAPTER XI

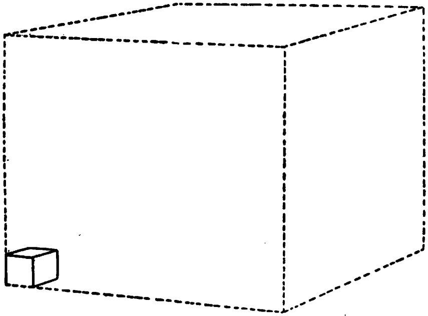
STEAM, BOILERS AND ENGINES

IF fire be ranked as the most useful acquisition made by man, surely the application of it in the production of steam as a source of power marks the advent of the supremacy of mankind over the forces of nature. When one sees a locomotive drawing hundreds and thousands of tons of freight across a continent, or looks upon a gigantic "Mauretania" forcing its irresistible way through a mighty ocean, against wind and tide, it is hard to realize that the tiny wisps of steam, occasionally escaping into the open air, are responsible for all this wonderful service.

Here is the secret of it all. A cubic inch of water when heated sufficiently will give about 1,700 cubic inches of steam, almost a cubic foot. This steam is made up of little molecules, moving backward and forward, up and down, in every conceivable direction, like tiny pendulums. The striking of these little hammers upon a restraining surface produces what is termed "pressure." If the cubic foot of steam derived from the cubic inch of water be confined in a space of say, one-half cubic foot, these hammers, bombarding the restraining walls, will strike with twice the force, and the pressure will be twice as great; if the space be made one-fourth, then the pressure will be four times as great.

Man has learned this simple secret just as the magician of old learned the magic word which enabled him to open the treasure house in the mountain side, and make himself rich. Nevertheless it has taken the world a long time to understand all this. The first man who dimly perceived it was the Marquis of Worcester, an Englishman, confined in the gloomy tower of London, owing to his loyalty to the ill-fated Charles I. This nobleman, in the weary days of his imprisonment, noticed that if a weight were placed on the lid of a tea-kettle, the enclosed steam would at regular intervals raise the weighted lid, and escape. The full significance of this phenomenon, however, escaped the distinguished observer, as he had only the slightest conception of its possibilities.

Worcester made an ingenious contrivance for the utilization of steam pressure, but in no sense was it an engine, as the term is used to-day. As a matter of fact, although Worcester is occasionally spoken of as the inventor of the steam engine, he had no thought of obtaining mechanical motion from steam power. This distinctive feature was in all probability applied, even if it was not discovered, by another Englishman, Thomas Newcomen, who made the first steam engine that was practical and "did things." The model of Newcomen's engine had been in possession of the University of Glasgow for over fifty years, and was used in the department of natural philosophy of that institution as an important aid in the teaching of this new and interesting subject.


One Cubic Inch of Water Gives 1,700 Cubic Inches of St.am

One day in the year 1763 the model broke, and it was

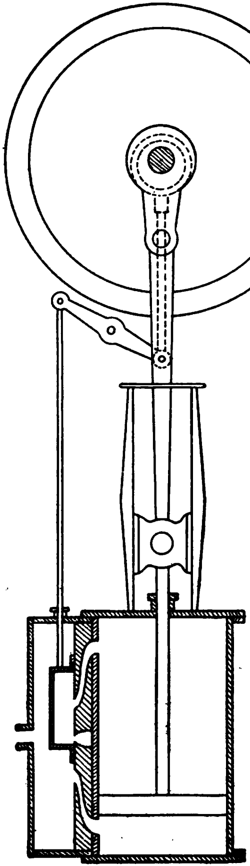


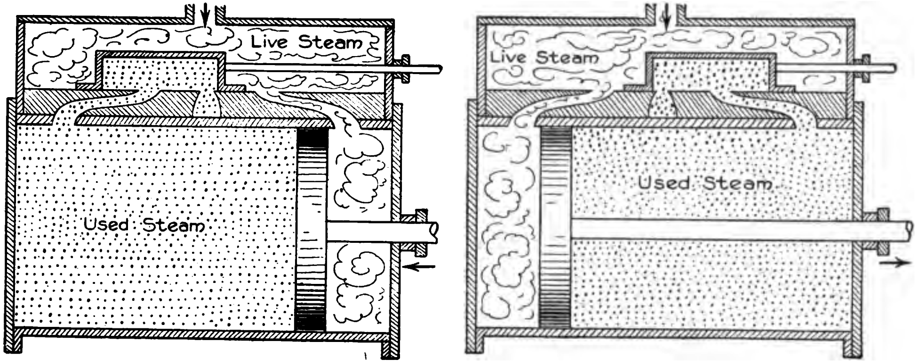
Diagram of Simple Steam Engine

sent for repairs to a young workman patronized by the University. The workman, who was no other than James Watt, was delighted with the opportunity thus afforded him of making a careful study at first hand of this wonderful machine. He repaired the model, but made such additional improvements that it was practically a new engine. If the credit of the discovery of the modern steam engine can be given to any one man, then that man is James Watt. In 1782, Watt patented his invention of the double-acting steam engine and the cut-off gear for making steam work expansively. Watt was also the first man to adapt the steam engine to the production of rotary motion, as he was the inventor of the crank in its application to the steam engine. Watt invented the governor, throttle valve, parallel motion, and the power indicator. As a matter of fact there has been only one great improvement in the steam engine since his time, namely, that of compound expansion.

By slow degrees the steam engine has developed into the almost perfect mechanism of today. Many brains have studied it, many hands have worked upon it. There are almost as many different types and forms of engines and boilers now as there are days in the year, but all of them owe their efficiency to the tiny little molecules causing pressure by everlastingly hammering away at steel restraining walls, some of which are fixed and immovable, and others that slip back and forth in their grooves of polished steel.

Water is the raw material for steam, and, fortunately, it is the best and cheapest material that can be used in the formation of vapor. Water has the highest temperature at the limit of pressure of practically all available fluids, and is therefore the most economical fluid as a vapor source, while its abundance, comparative purity, and cheapness place it far beyond any other liquid that might rival it as a vapor producer.

Water has a very high specific heat, and an enormous



The Simple Steam Engine, Showing Typical Positions of Slide Valve amount of heat energy is needed to change it at 212° F. into steam at the same temperature, no less than 968.4 British thermal units. In other words, the energy needed to transform a pound of water at the boiling point into steam at the same temperature would raise almost a half ton of water one degree in temperature. After water has become steam, it heats more readily, as only .48 heat units are required for each degree the temperature is raised. Steam is not energy. Like electricity, it is simply a carrier of energy from the fuel to the machinery that does the mechanical work.

Saturated steam is the term applied to steam that is given off by boiling water, and is, of course, invisible. The familiar white cloud we see emanating from a steam pipe owes its color to the partial condensation that has taken place. Saturated steam owes its temperature to its pressure, and may be either wet or dry. Superheated steam, now coming so commonly into use, is steam that is heated to a temperature above that due to the pressure, and this heating must be done outside of the pressure of the water from which it was generated. Superheated steam, of course, contains more energy than the saturated form.

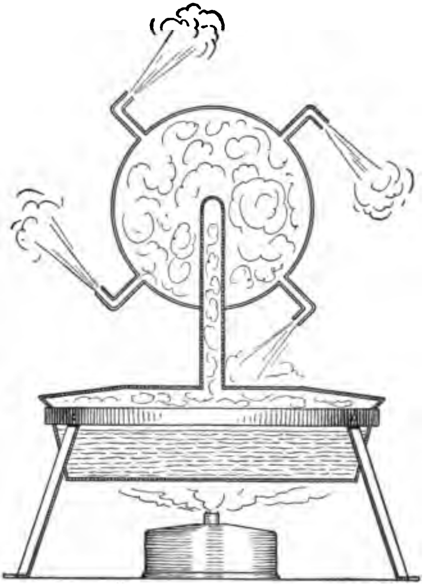
There is a limit to the heating of steam, however, as it will disassociate into its constituent gases, oxygen and hydrogen, beyond a certain point known as the critical temperature. One great advantage possessed by superheated steam is the fact that it cannot condense until it has lost all of its superheat and is reduced to the saturated form. As there is always a loss of heat by radiation where steam is conveyed in pipes, this loss in the case of superheated steam will simply lower the temperature of the superheat, but not enough to cause it to become wet, as in the case of saturated steam. Dry steam, of course, has a much higher efficiency than wet steam. Superheated steam is clearly indicated in the use of turbine engines, as the energy of the steam is transformed directly into velocity.

Were there any condensation, the water thus formed would interfere with this result, and would also produce corrosion and wearing away of the blades. The extra fuel required for superheating is comparatively slight, as 250 degrees of superheat may be secured at a cost of only 20 per cent additional fuel. One disadvantage in the use of superheated steam, in the case of turbines, is the tendency to produce warping in the blades due to high temperature.

The evolution of the boiler from the simple box used by Hero of Alexandria, about 130 B. C., to the modern tubular type of to-day is extremely interesting, and in every respect it has more than kept pace with the development of the engine. A modern boiler is distinctively a work of art and a triumph of science. Whether the material used be malleable iron, cast iron, wrought iron, steel, copper, or various compositions such as bronze or nickel steel, every part of it is tested for tensile strength, compression strength, torsional strength, shearing strength, and resistance to bending.

So far as construction is concerned, boilers may be classed into two general divisions. The water-tube type, and the fire-tube type. As has already been indicated in the course of these chapters on Heat, water is an extremely hard matter to heat. The old type of "tea-kettle" boilers, where the water is confined in one mass, is far from economical, at least so far as the time required to "get up steam" is concerned. It was soon perceived that the mass of water in the boiler must be divided, in order to obtain more heating surface. Therefore, practically all modern boilers are either of the fire-tube or water-tube form. In the fire-tube type, as the name would indicate, the hot gases are forced to travel from the firebox to the chimney through tubes surrounded by water. In the water-tube boilers, the tubes are filled with water and are completely enveloped by the hot gases passing over and among them, in the journey from firebox to chimney. In both types, practically the same result is obtained, namely, the exposure of relatively small quantities of water to abundant heating area.

Which of the two forms is the more economical and efficient, is a mooted question among engineers. There is no doubt but that the water-tube form is safer, especially when steam above 150 lb. is used. The water-tube form also takes less time to raise steam, due to the better circulation obtained than in the fire-tube. The rapid circulation in a water-tube boiler is due to the fact that as the water in the tubes in the hottest part of the boiler



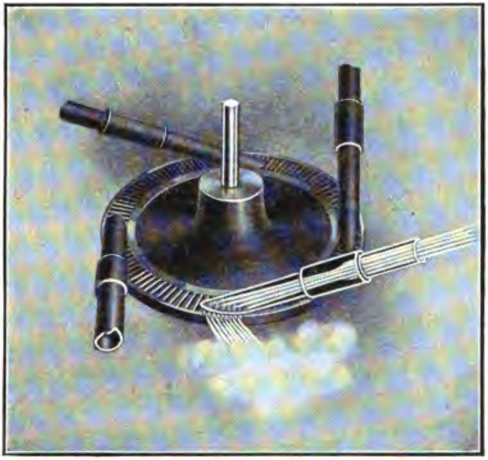
The First Turbine Engine Constructed by Hero of Alexandria

turns into steam, it is rapidly replenished by the rising of the cold water.

In practice, it has been found that a fire-tube boiler requires from two to two and one-half hours to raise steam to its working pressure, while steam may be raised to the same point in a water-tube boiler in less than an hour. If the time element is to be considered, the water-tube is therefore the more advantageous of the two. Unfortunately for boiler practice, it is hard to procure pure water. Even the purest of natural waters contains some mineral constituents, and the constant distillation of the water to form steam leaves these mineral salts as incrustations and sediments that interfere not only with the steaming capacity of the boiler, but also with its life. In a former chapter, the effect of dirt and grime on the outside of the boiler was mentioned, and the serious loss of fuel efficiency due to this cause was commented upon. The incrustations within the boiler have even a greater effect upon the efficiency. It has been estimated by conservative engineers that a layer of scale one-fourth inch in thickness causes a loss of 35 per cent in fuel, while half an inch of scale will result in a loss of from 55 per cent to 65 per cent.

An ordinarily good water will contain about 25 grains of mineral matter to the gallon. A stationary boiler of about 160 hp. capacity will evaporate 600 gal. of water per hour. This would mean a deposit of 15,000 grains per hour, or, as there are 7,000 grains in a gallon, 2 1/7 lb. of mineral matter will be left behind by the steam every hour. Suppose the boiler were worked a month of 25 days of 10 hours each, without cleaning; the hard scale and sludge formed would produce the enormous total of over five hundred pounds.

The corrosion produced in boilers by certain impurities such as acids, grease, gases, organic matter, and so forth, greatly weakens the shell, and is a frequent cause of explosions. Numerous safety devices for boilers have been patented, and many peculiarly constructed boilers have been put on the market, guaranteed to be absolutely explosion-proof, but as a matter of fact, there is no such thing as a boiler that cannot explode. The only safeguards are first-class material, careful and frequent inspections, and competent attendants who make it their business to watch carefully the needs of their charges. A boiler, like a human being, has a normal life, and experience tells us that while certain types may last for 20 or 30 years, other forms, such as locomotive boilers, rarely last six years.



Simple Turbine Engine

Steam engines may be classified in several ways. First, as regards speed; second, as regards number of cylinders; third, the method of exhaust; fourth, the position of the engine, whether it be horizontal or vertical. A slow-speed engine has a long stroke but comparatively few revolutions per minute, while the high-speed type is distinguished by the shortness of its stroke and the greater number of revolutions per minute. A simple engine is one that has only one cylinder, and the steam is therefore used but once. If the exhaust steam is turned into a second cylinder and used a second time, the engine is a compound form. If a third cylinder be added, and the steam, originally at high pressure, passes through two other cylinders at successively lower pressures, the type is known as a triple-expansion engine. The cylinders of a compound engine may be placed in a direct line with each other and have a common piston rod. Such an engine is known as a tandem compound. If the two cylinders are placed opposite each other, the engine is known as a cross-compound, or cross-connected. A compound engine is of course more efficient than a simple engine, due to the fact that the energy still remaining in the exhaust steam is utilized. With the same amount of fuel, the compound engine will develop more power than the single type.

An engine that exhausts directly into the air against the atmospheric pressure is known as a high-pressure engine, and must work against an air pressure of 15 lb. to the square inch. A condensing engine, as its name would indicate, is one that condenses the exhaust steam, relieving the back pressure and adding that much to the efficiency of the engine.

The work done by an engine is calculated in horsepower. A horsepower is the ability to raise 33,000 lb. one foot in one minute, or 550 lb. one foot in one second. The horsepower of an engine may be calculated by using the formula $\frac{PLAN}{33,000}$ in which P represents the effective pressure, L is the length of stroke, A is the area of the piston in square inches and N is the number of strokes of the piston rod per minute.

Considering the question of power given to work done, a steam engine is an extremely wasteful device. The ordinary non-condensing engine rarely has an efficiency of more than 10 per cent, and is generally far below that percentage, and consumes from two to three pounds of coal per horsepower hour. The introduction of the compound, triple-expansion, and quadruple-expansion types of engine has raised the efficiency considerably, lowering the consumption of coal to one pound per horsepower hour. Nevertheless the greatest efficiency yet obtained in a steam engine does not exceed 25.5 per cent, and this is obtained in the Nordberg quadruple-expansion engine.

The steam turbine, which is really a modified water-wheel driven by steam instead of water, is rapidly coming into favor, especially on ocean-going vessels. The turbine occupies less space than the ordinary reciprocating engine, is practically free from vibration, and has the great advantage of uniform and high angular velocity. Its efficiency as compared with the best reciprocating engine is about the same, but owing to the advantages named is gradually supplanting the older types of engines.

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